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Empirical Validation of the Conceptual Design of the LLNL 60-kg Contained-Firing Facility

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Lawrence Livermore National Laboratory

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Abstract

In anticipation of increasingly stringent environmental regulations, Lawrence Livermore National Laboratory (LLNL) is proposing to modify an existing facility to add a 60-kg firing chamber and related support areas. This modification will provide blast-effects containment for most of its open-air, high-explosive, firing operations. Even though these operations are within current environmental limits, containment of the blast effects and hazardous debris will further drastically reduce emissions to the environment and minimize the hazardous waste generated.

The major design consideration of such a chamber is its overall structural dynamic response in terms of its long-term ability to contain all blast effects from repeated internal detonations of high explosives. Another concern is how much other portions of the facility outside the firing chamber must be hardened to ensure personnel protection in the event of an accidental detonation while the chamber door is open.

To assess these concerns, a 1/4-scale replica model of the planned contained firing chamber was engineered, constructed, and tested with scaled explosive charges ranging from 25 to 125% of the operational explosives limit of 60 kg. From 16 detonations of high explosives, 880 resulting strains, blast pressures, and temperatures within the model were measured to provide information for the final design.

Executive Summary

Based on measurements obtained from scaled detonation experiments within a 1/4-scale replica model, factors of safety for dynamic yield of the firing chamber structure were calculated and compared to the design criterion of totally elastic response. The rectangular, reinforced-concrete chamber model exhibited a lightly damped vibrational response that placed the structure in alternating cycles of tension and compression. During compression, both the reinforcing steel and the concrete remained elastic. During tension, the reinforcing steel remained elastic, but the concrete elastic limit was exceeded in two areas, the center spans of the ceiling and the north wall, where elastic safety factors as low as 0.66 were obtained, thus indicating that the concrete would be expected to crack in those areas. Indeed, visual post-test inspection of those areas revealed tight cracks in the concrete.

Internal blast pressures averaged 2 to 3 times greater than expected. Quasistatic gas pressures peaked at 18 psig, roughly 86% of the 21 psig predicted by calculation.

External blast overpressures from an accidental detonation scenario ranging from 0.1 to 70 psig were measured during the open-door tests at 22 locations outside the firing chamber model.

In general, these experiments have demonstrated that a rectangular, conventionally reinforced, concrete structure can be used as a firing chamber. More specifically, they have validated the conceptual design prepared by the architectural/engineering firm of Holmes and Narver.

Rationale for Contained Firing

Since 1955, Lawrence Livermore National Laboratory (LLNL) has conducted open-air explosives detonations at its Site 300 remote test complex. The Laboratory uses its explosives test facilities to precisely measure critical variables of importance to nuclear weapon designs, to test conventional ordnance designs, and to evaluate possible accidents (such as fires) involving explosives. Although emissions to the environment from open-air testing at LLNL's facilities currently do not exceed current environmental standards, this may not always be the case.

In anticipation of stricter environmental regulations and because of the Secretary of Energy's mandate that environmental, safety, and health (ES&H) concerns be the first priority at all U.S. Department of Energy (DOE) facilities, LLNL is developing a comprehensive, state-of-the-art, blast-effects containment (or contained-firing) facility (CFF) (see Fig. 1). This is needed to reduce emissions of hazardous materials and the amount of contaminated wastes generated by explosives testing while providing a continuing capability to test nuclear and other assemblies that contain high explosives. A permanent, state-of-the-art firing chamber is to be constructed around and integrated into an existing facility's open-air firing surface to completely contain blast effects and thereby enhance environmental protection, waste minimization, and safety for the 21st century.[1]

CFF Description

The CFF project consists of adding about 2463 m^2 of structural additions to the existing open-air firing facility at Bunker 801, the site of LLNL's existing world-class 17-MeV flash x-ray (FXR) machine. Bunker 801 already contains a variety of high-speed optical and electronic diagnostic equipment, which, together with the FXR, provide unique diagnostic capability. The new additions consist of four components: a firing chamber, a support area, a diagnostic equipment area, and an office / conference module, as shown in Fig. 2.

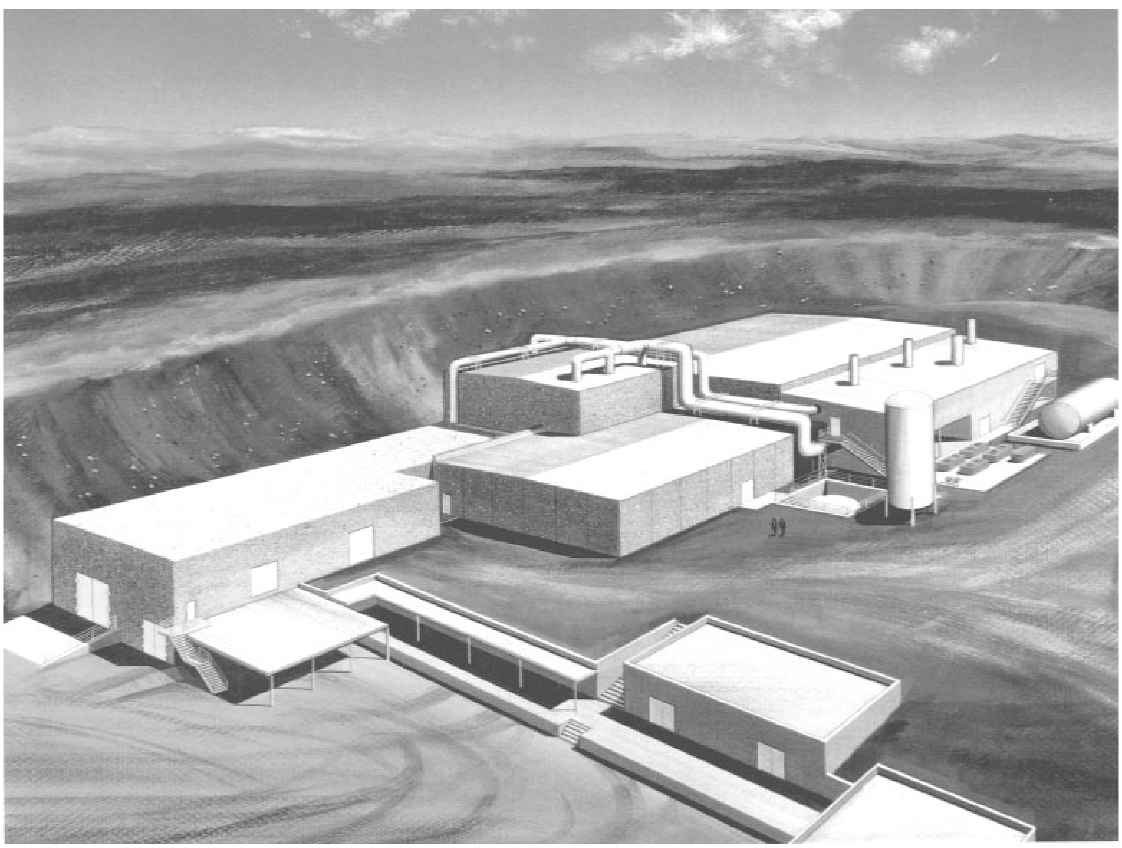


Figure 1. Artist's concept of the planned Contained Firing Facility.

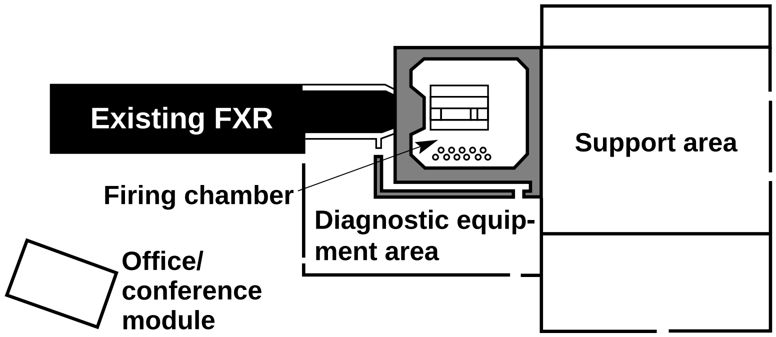


Figure 2. Plan view of the proposed Contained Firing Facility additions to Bunker 801.

The heart of the CFF is the firing chamber (see Fig. 3). Slightly larger than half a gymnasium, the firing chamber will contain the blast overpressure and fragmentation effects from detonations of cased explosive charges up to 60 kg. The inside surfaces of the chamber will be protected from high-velocity shrapnel that results from detonating cased explosives. To permit repetitive firings, all main structural elements of the firing chamber are required to remain elastic when subjected to blast. Detonations will be conducted above a 150-mm-thick steel firing surface (the shot anvil) embedded in the floor.

Explosive quantity zones, with capabilities for operational masses up to 60 kg of PBX-9404 (a plastic-bonded explosive containing 94% HMX)[2] or an equivalent TNT mass of 78 kg, are shown in Fig. 3 for detonations at the nominal distance of 1.22 m above the anvil surface. Separate, general-purpose, removable shielding protects the

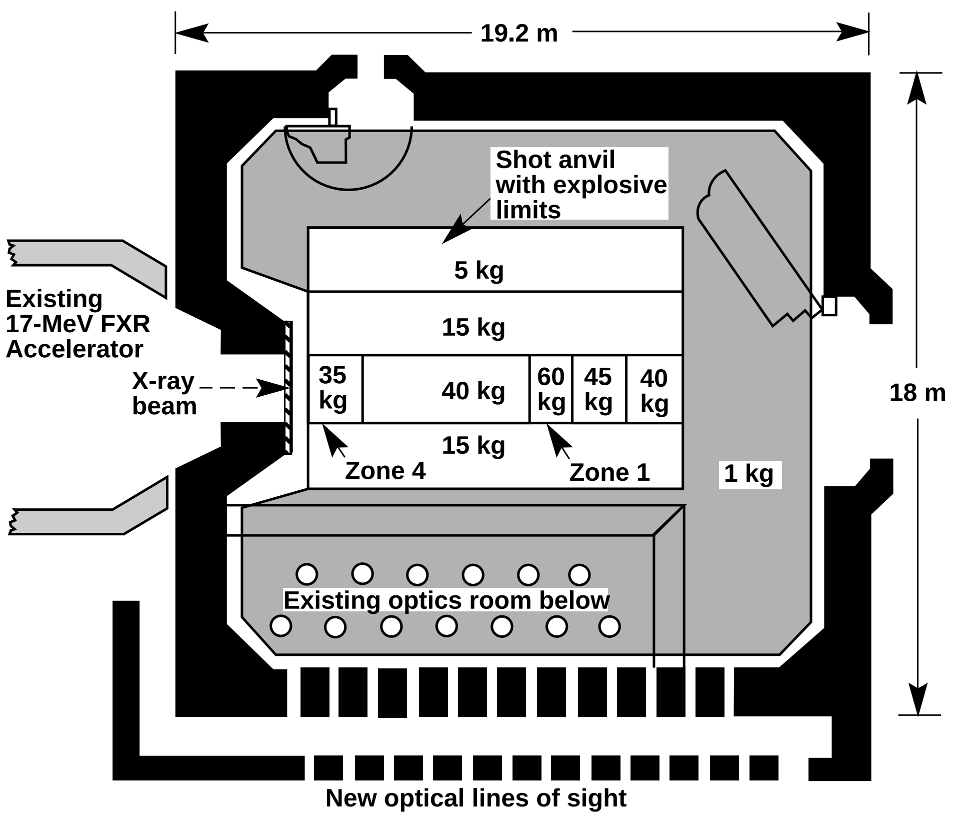


Figure 3. Plan view of the firing chamber, showing shot detonation zones, with corresponding high-explosive mass limits.

interior surfaces of the firing chamber from high-velocity fragments. A key aspect of the CFF is that the rectangular concrete firing chamber will be made with low-cost, conventional reinforcement, as opposed to the labor-intensive, laced reinforcement commonly found in many blast-resistant structures. From a materials standpoint, a spherical chamber shape would be more blast efficient, but a slightly heavier, rectangular shape is cheaper, provides easier and more desirable setup and working surfaces, and encompasses existing diagnostic systems. The thickness of the reinforced concrete walls, ceiling, and floor of the chamber are 1.22, 1.37, and 1.83 m, respectively.

The locations of existing camera ports and the end of the FXR accelerator (see Fig. 3), all of which must be in the chamber, led to the selection of a chamber area of about 344 m^2, with an interior height of 9.5 m.

The support area (about 1543 m^2) provides a staging place for preparing the nonexplosive components of an experiment, equipment and materials storage, personnel locker rooms, rest rooms, and decontamination showers. It also houses the filters, scrubbers, and a temporary waste-accumulation area for the waste products from testing.

The diagnostic equipment area (about 576 m^2) will accommodate multiple-beam optical equipment to measure, through 12 horizontal optical lines of sight (LOSs) into the firing chamber, velocity-time histories from as many as 40 points on an explosively driven metal surface. These are in addition to 11 vertical optical LOSs from the existing camera room situated below the chamber floor. The diagnostics area is similar in construction to the support area and will also protect personnel who may occupy it during explosives tests.

Design Equivalency Criteria

The criterion for the design of the CFF is that it be able to elastically survive the blast effects from detonating up to 60 kg of an energetic explosive such as PBX-9404. Designing the chamber to survive this environment requires an equivalency conversion in the structural design process from energetic material to the de facto standard (TNT). The equivalent TNT mass is based on a single-worst-case equivalency factor that encompasses all maximum effects from blast and quasistatic gas pressure (currently used at Site 300). This factor (β) is defined as the largest ratio of the heat of detonation for energetic materials to that of TNT:

$$\beta = \max\left(\frac{\Delta H_{\text{energetic material}}}{\Delta H_{\text{TNT}}}\right) \equiv 1.3 \quad . \tag{1}$$

Due to variations in high-explosive charge initiation and the inaccuracies associated with construction materials, a safety factor of 1.2 is additionally specified[3] in the design equivalency process. The amount of TNT equivalent for structural design purposes is thus given by

$$\text{Mass of TNT design equivalent} = \beta \cdot 1.2 \cdot [\text{desired HE operational mass}] \quad . \tag{2}$$

For the CFF, this amounts to

$$\text{Mass of TNT design equivalent} = 1.3 \cdot 1.2 \cdot 60 \text{ kg} = 93.6 \text{ kg} \quad , \tag{3}$$

which is the basis of all the design calculations by the architect/engineer (A/E).

Environmental Considerations

"Contained firing" implies complete containment of all blast effects associated with the detonation of cased high-explosive materials. This includes discharges to the environment in the form of noxious gases, particulate matter (aerosolized and chunky), and impulsive noise produced from the detonation. Although it is highly desirable to have a "zero discharge" criterion as a goal of the CFF project, it is recognized that this is nearly impossible to achieve and is excessively expensive to implement. Instead, the CFF project is based on a "near-zero discharge" policy, whereby small discharges that are within all environmental regulations may occur from time to time over the anticipated life of the facility. The distinction between the two is important socially and politically, in that small, environmentally acceptable, accidental discharges may result in closure of the facility if they are not anticipated and publicly acknowledged early in the design process.

The firing chamber will be a sealed structure that will contain not only very high-amplitude, short-duration impulsive shock pressures but also the much lower amplitude and longer duration quasistatic gas pressures that are typical of explosives detonated in closed firing chambers. Anchored to the inside of the concrete chamber surfaces is a thin, continuous, 12.7-mm-thick, mild-steel pressure liner, which will seal and prevent the detonation gases from passing through the concrete walls, ceiling, and floor, all of which may develop structurally acceptable hairline cracks as the facility ages. All doors, optical LOSs, and other intrusions into the firing chamber (such as the FXR bullnose) will have seals that allow the firing chamber to function as a pressure vessel to contain the blast and quasistatic pressure. After the gases cool, blast dampers will open, and ventilation fans will purge the chamber with fresh air. The exhaust gases will be processed through HEPA (high-efficiency particulate air) filters and scrubbers before being released to the environment. Slight negative atmospheric pressures will be maintained afterward in the firing chamber and the support area to reduce the escape of unprocessed airborne hazardous particulates and gases to the environment.

Solid wastes and shot-related debris will be greatly diminished and can be collected and disposed of as low-level radiated waste or as mixed waste. In conjunction with management of these solid wastes, a reactive-waste certification program is being developed at LLNL. An internal, closed, water wash-down system is planned that will recirculate water spray within the chamber and filter out dust and particulates in the form of sludge. The CFF project will aggressively minimize waste by reducing the total solid waste to about one-tenth of the amount generated today.

Blast-Effects Supplemental Testing

After review of the CFF conceptual design report (CDR),[4] four critical blast-effects design issues were identified that, due to their variability, would benefit from further investigation. A four-part program, primarily based on blast effects testing, was formulated in each of the following four areas:

- Shrapnel mitigation
- Close-in shock loading
- Qualification and acceptance testing
- Total structural response.

The focus of this report is the total structural response obtained by testing a 1/4-scale model of the firing chamber. The rationale for each of the other three testing programs is described briefly in the following sections.

Shrapnel Mitigation

High-velocity fragments from cased explosives could do significant damage to the pressure liner in the firing chamber and thereby compromise the containment and sealing of hazardous gases and particulates. Worst-case, shrapnel-producing experiments at Site 300 were monitored and documented[5] to evaluate various general-purpose shrapnel-protection schemes. The resulting design, shown in Fig. 4, is a replaceable, general-purpose, multilayer, protection scheme to be installed on the inside concrete surfaces of the firing chamber. From this testing program, three important design modifications to the conceptual design could be realized:

- Additional local shielding would be required on an as-needed basis near those experiments that produce material with a directional nature (e.g., shaped charges). Addition of localized shielding would permit the overall general-purpose shielding to be thinner, resulting in a cost saving.
- General-purpose shielding made from mild steel instead of armor plate would be used because mild steel is roughly half the cost and provides about 85% of the penetration resistance of armor plate.

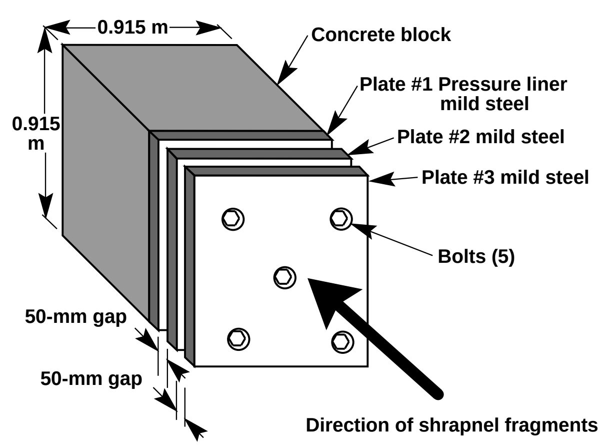


Figure 4. Shrapnel-mitigation testing apparatus.

• Multilayer technology would be used, whereby thinner shrapnel-mitigation plates are separated by air spaces, thereby permitting the total thickness of shielding to be reduced and facilitating replacement and repair.

Close-in Shock Loading

The highest unit shock (blast) loading that the CFF must withstand will occur on the floor just below the 60-kg explosive charge location. Currently, due to diagnostic requirements of the FXR and the desired operational optical LOSs, this distance is 1.22 m. This results in an extremely close-in ($Z = 0.66$ ft / lb$^{1/3}$) blast loading on the reinforced concrete floor of the chamber. Historically, floor damage from close-in loading has been a common problem for many blast chambers within the DOE / DoD (Department of Defense). Given this, the close-in blast loading on the chamber floor is considered to be one of the critical design issues for the proposed CFF. To investigate this concern, a series of 19 close-in blast loading experiments was conducted on a 1 / 4-scale section of the proposed floor design (see Fig. 5). The following conclusions were reached as a result of this testing.[6]

• Tensile strains in the concrete were 10 times the allowable dynamic tensile yield and would be likely to cause severe concrete cracking and pulverizing in the long term.

• A low-cost blast attenuation system was developed and tested that reduced the measured strains in the concrete to acceptable elastic levels to prevent severe pulverizing of the concrete.

• Measured strains in the reinforcement, the bolts, and the anvil were all within elastic limits for steel.

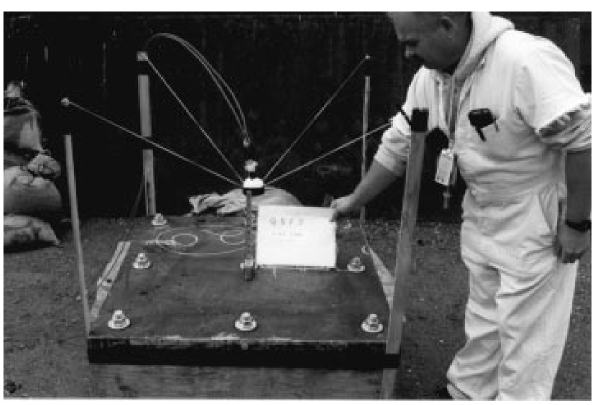


Figure 5. 1/4-scale floor section prior to testing at the 25% explosive weight level.

Qualification and Acceptance Testing

After the CFF is constructed but before it is used for normal experiments, a series of qualification / acceptance tests will be performed in the firing chamber to test it and the support systems. Explosives tests that produce up to 125% of the chamber pressure capacity are required by LLNL policy[7] to further ensure that the facility has been safety constructed and that it meets or exceeds the original design criterion of totally elastic response. As with the 1 / 4-scale model of the firing chamber, the actual firing chamber will be instrumented with permanent gauging to assess the effects of the required qualification tests. The permanent strain gauges and pressure transducers can then be monitored at any time during detonations over the anticipated life of the firing chamber to ensure safe and reliable operation.

The remainder of this report describes 16 blast tests conducted in a quarter-scale model of the preliminary or conceptual chamber design.

Total Structural Response Experiments—Firing Chamber Scale Model

Introduction

It is customary and good engineering practice to build and test scale models of high-value, blast-resistant structures before the actual full-size structures are constructed. Testing of an instrumented scale model is particularly useful in verifying the preliminary design because it reveals potential construction defects and provides the best estimate of the actual blast loading environment for use in the final design. Recent experience from qualification testing of the contained firing vessels in the High-Explosives Applications Facility (HEAF)[8] at the LLNL main site indicates that, in some regions, the highest measured strains occur after the shock loading has passed and are due primarily to the vibrational modes of the structure that are excited by the impulsive nature of the detonation.

To evaluate the CDR chamber design, a 1 / 4-scale replica model of the firing chamber was engineered, constructed, and instrumented with strain gauges, pressure transducers, and temperature gauges (see Fig. 6).

Closed- and open-door tests were conducted by detonating high-explosive charges within the model. For the closed-door tests, the chamber was sealed to measure the normal maximum interior pressures, strains, and temperatures that would be expected on a routine, day-to-day basis (100%) and from qualification/acceptance over-tests at 125%. As a result of confinement, realistic blast loadings with multiple reflections off of the ceiling and walls occurred, as did long-term quasistatic gas loadings.

Leaving the chamber door open during some experiments permitted outside blast pressures to be measured that could affect adjacent structures in the event that an accidental detonation occurs while a shot is being set up in the firing chamber. These blast measurements were used by the CFF A/E to assess and design adequate facility hardening (i.e., protection for those personnel who would not be directly involved in the pending explosive experiment, especially personnel in the locker room, the clean diagnostics area, and the small office/conference area).

Design Considerations

A scale factor of 1/4 was chosen as a compromise between modeling scalability, cost, and internal accessibility. Since the rationale for testing was to verify that the overall or global response was within limits, nonessential design details and features specified in the CDR intentionally were left out of the scale model to keep the cost reasonable and the model simple.

In some cases, the deviations were improvements that made the model stronger or easier to build. It was further recognized that the CDR was, by nature, a preliminary design and was not intended to be a complete design. Therefore, some design details were based on established civil engineering practice and code regulations. The major additions and/or deviations from the CDR and the rationale for making them were as follows:

• **Substituted single-level floor.** The CDR called for a split-level floor that would be integrated with the existing camera room roof. The effect of the split level with intermediate support would have been a stronger and much more expensive scale model to construct. Instead, a single slab floor was constructed that, due to its longer span, would be weaker and thus would provide a more conservative verification of the conceptual design.

• **Used equivalent replica scaled rebar.** Exact replica (or geometric) scaling of the steel reinforcing bars (rebar) could not be achieved by using conventional common sizes. Instead, equivalent scaling was used by adjusting the in-plane rebar spacing and size to try to maintain the CDR ratio of rebar to concrete. A comparison of the flexural reinforcement between the CDR and the 1/4-scale model is provided in Table 1.

• **Simplified wall-to-floor joint.** The CDR called for a notch or keyway in the concrete floor into which the walls would be tied and poured. Instead, upon advice from our civil engineers, this keyway joint was eliminated in favor of a simple, flush, butting connection between the floor and walls. As a result, the moment resistance of this joint would not be compromised and, for the purposes of our testing, the sealing capability would not be affected either. This again simplified the model design and reduced construction costs.

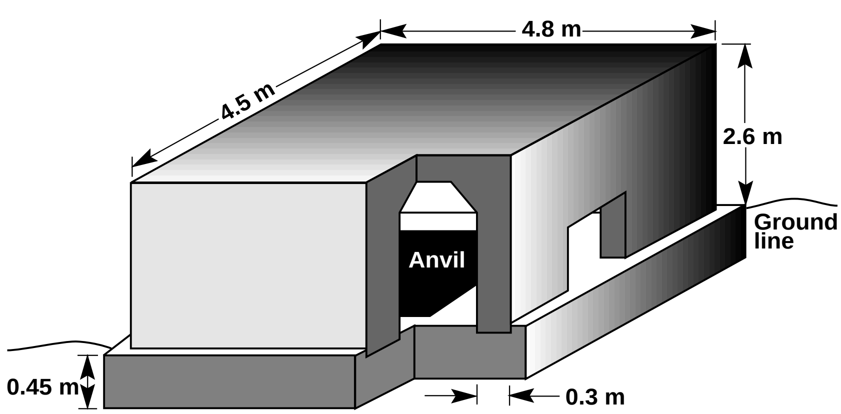


Figure 6. Quarter-scale model of the firing chamber.

Table 1. Flexural reinforcement comparison between CDR and 1/4-scale chamber model.

	CDR						1/4-scale model						
Reinforce-ment area	Bar size	No. bars	Shear area per bar (in.^{2})	Spacing (in.)	Concrete thickness (in.)	Reinforce-ment ratio	Bar size	No. bars	Shear area per bar (in.^{2})	Spacing (in.)	Concrete thickness (in.)	Reinforce-ment ratio	% difference from CDR[a]
Walls, vert., inner	11	5	1.56	10	48	0.016	11	1	1.56	6	12	0.022	+33
Walls, vert., outer	11	3	1.56	10	48	0.010	7	1	0.6	6	12	0.001	–15
Walls, horiz., inner	11	3	1.56	10	48	0.010	8	1	0.79	6	12	0.011	+13
Walls, horiz., outer	11	2	1.56	10	48	0.007	6	1	0.44	6	12	0.006	–6
Roof, lower mat	11	4	1.56	10	54	0.012	6	2	0.44	6	13.5	0.011	–6
Roof, upper mat	11	4	1.56	10	54	0.012	6	2	0.44	6	13.5	0.011	–6
Floor, upper mat	11	5	1.56	10	72	0.011	6	2	0.44	6	18	0.008	–25
Floor, lower mat	11	4	1.56	10	72	0.009	7	2	0.6	6	18	0.011	+28

[a] – means decrease from CDR
+ means increase from CDR

• **Eliminated diagnostic viewports.** Details for optical port designs were not included in the CDR. Additionally, because the ports were so much smaller than the firing chamber, it was thought that the stress concentrations around the ports would be very limited and localized. Simple pipe-and-flange ports were added to the model to facilitate flush-mounting the internal blast-pressure transducers on the inside surfaces of the chamber. These were typically ports with a 2-in. clear aperture but with steel blank flanges mounted instead of port glass. A large, 12-in., clear-aperture port was added for future experiments to help assess double-port glass-mounting schemes developed in HEAF. The 12-in. port was sealed off during testing with blank steel flanges.

Two 6-in. ports also were added in the roof at the northeast corner and in the south wall near the floor at the east wall corner. The 6-in. roof port was valved to allow the chamber to vent quasistatic pressure before reentry. The 6-in. wall port was fitted with a feedthrough to hold the detonator wires for firing the shots. The ports were located diagonally opposite each other for future experiments involving gases other than air to reduce the blast effects.

• **Reduced coverage of general-purpose shrapnel-protection plates.** Due to their low relative mass compared to the thick walls of the chamber, it was assumed that the shrapnel protection system and pressure liner would have a neglible effect on the overall dynamic structural response of the chamber. However, an area of concern is the rebounding of the pressure liner, which is anchored to the walls. The mass of the pressure liner and bolted-on shrapnel-protection plates produce significant inertial forces that have to be reacted through the anchors when the walls resonate due to the blast. To investigate this behavior and keep the construction costs reasonable, a 0.92- by 0.92-m section of the pressure liner and general-purpose shrapnel-protection system was added to the north wall of the model. The shrapnel-protection system was located at the center span of the wall, where it was expected to encounter the greatest rebound acceleration.

• **Simplified blast /equipment access door.** Since the CDR did not contain details of the large 3.6- by 4.3-m blast door and framework, a simple two-plate door system was used for personnel access and containment of the expected internal quasistatic pressure.

• **Eliminated nonstructural features,** such as the water wash-down and associated floor-drainage systems, the ventilation system, utilities such as electricity and gas, and personnel-safety systems.

• **Used unscaled concrete aggregate**. No attempt was made to scale the concrete aggregate for the scale model because it is believed to have little or no impact on the dynamic response of the firing chamber. The aggregate size was reduced from that in the CDR (3/4 in. max.) to 3/8 in. for ease of installation, especially at the corners and other areas that were highly congested with rebar. The overall concrete compressive strength remained the same (6 ksi nominal).

Construction

The 1/4-scale model of the firing chamber was constructed within the shot table area of Bunker 812 at Site 300. Laboratory engineers made construction drawings from the CDR with the previously mentioned exceptions. Specifications for procurement/fabrication were then prepared with the assistance of LLNL's Plant Engineering Department, and fabrication was awarded to a contractor. Construction commenced on November 28, 1993, and was completed on January 22, 1994. The 1/4-scale model of the firing chamber met all of the contract specifications and was accepted on February 28, 1994. Appendix B contains the "as built" revisions of the construction drawings.

The reinforced-concrete firing chamber model was constructed in two separate pours that totaled 28 yd^3 of concrete. The chamber floor was poured first, and the roof and sides then were formed up and poured one month later (see Figs. 7, 8, and 9). Per the CDR, conventional unlaced steel rebar was used throughout the scale model. The chamber floor consisted of a rectangular, 16.75- $\times$ 15.75- $\times$ 1.5-ft reinforced-concrete slab set on a compacted base foundation. The base foundation started with 12 in. of compacted soil with a dry density of 104 lb/ft^3 topped off with an additional 8 in. of class II aggregate base rock with a dry density of 142 lb/ft^3 (see Ref. 9). A sample of the compacted base foundation was measured at 91.8% relative compaction.[10]

Concrete with a minimum compressive strength of 6000 psi was used per the CDR. For better placement, a plasticizer was added per the manufacturer's specifications. Cylinder test data[11] showed the strength to be an average of 6050 psi at 28 days for the floor and 6200 psi for the rest of the chamber. Both pours were given a full, 10-day water cure.

The flexural steel reinforcing consisted of conventional grade 60 rebar tied in two parallel mats. The spacing between the floor, ceiling, and wall mats was nominally set to 15, 8.5, and 7.5 in., respectively. Table 1 lists the flexural reinforcing used to construct the model.

The steel shear reinforcing used was #3, grade 60 rebar on 6-in. centers throughout the chamber.

To model the 6-in.-thick shot anvil, a single 7.5-ft $\times$ 7-ft $\times$ 1.5-in. mild-steel plate was inset and flush-mounted with the top surface of the floor. After both concrete pours had cured, high-strength expansive grout[12] was pumped through special access holes in the anvil to eliminate voids and improve the contact between the bottom of the anvil and the concrete. The holes were then sealed with standard pipe plugs. After the grout

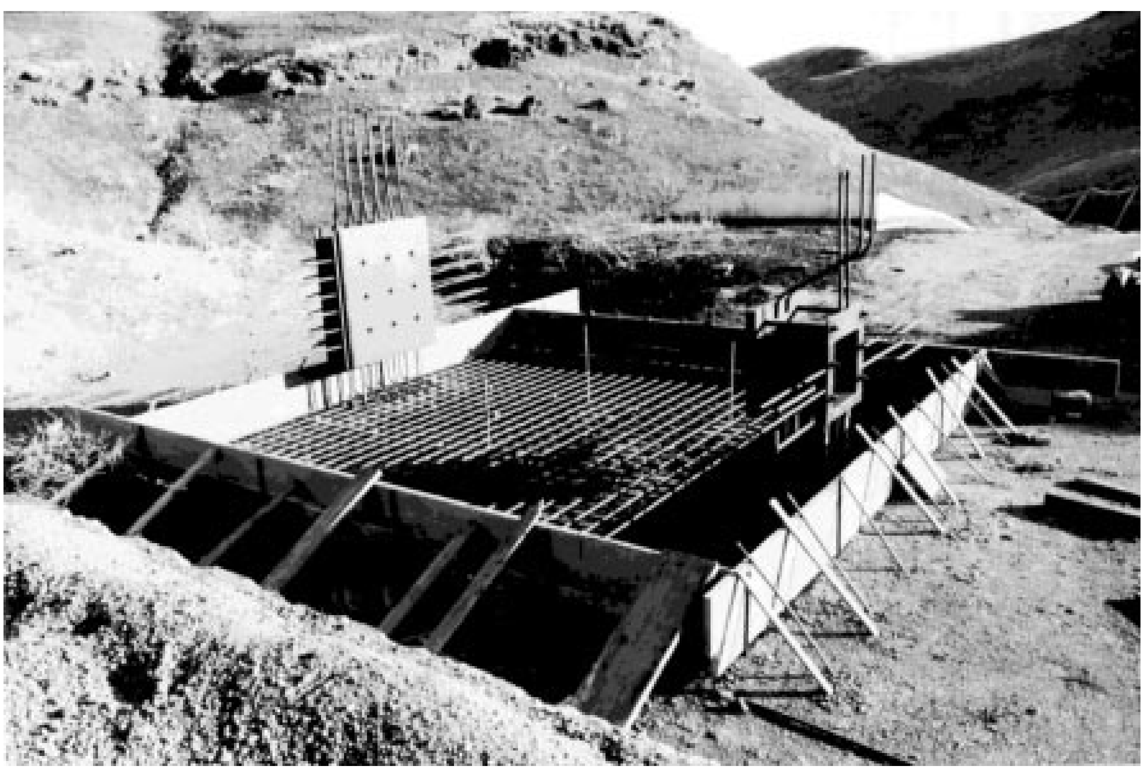


Figure 7. Early construction, showing embedments for the door (left) and bullnose (right).

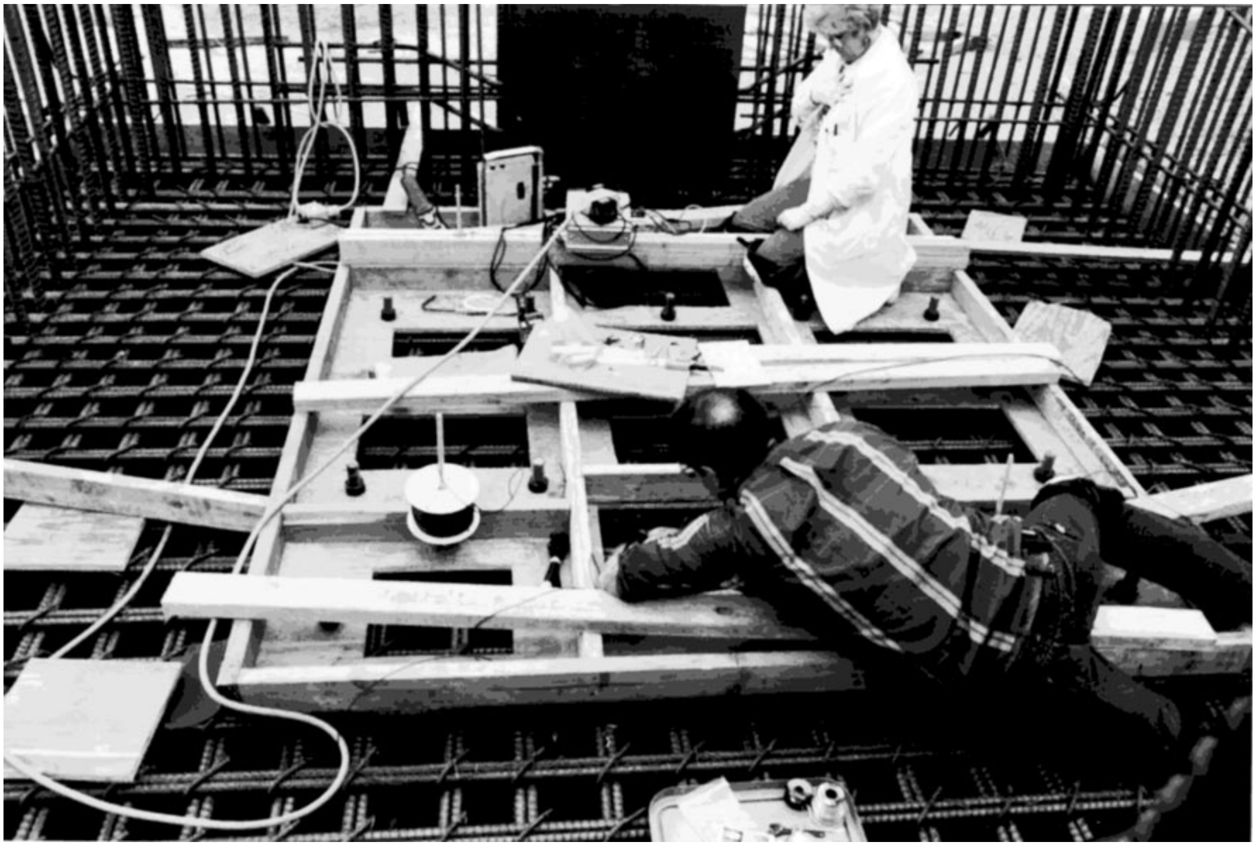


Figure 8. Technicians installing strain gauges in chamber prior to pouring concrete floor.

Figure 9. Final gauge installation prior to pouring walls and ceiling.

cured, the shot anvil was secured to the floor with 25 1-in. × 9-in.-long bolts torqued to 200 ft-lb.

A 3-ft × 3-ft square section of the pressure liner and general-purpose shrapnel-protection system was added to the inside surface on the north wall of the 1/4-scale model (see Fig. 10). The general-purpose shrapnel-protection system was a three-layer design—a thin pressure liner followed by two layers of shrapnel protection plates. The 1/8-in.-thick pressure liner had 1/8-in.-diameter by 4.25-in.-long J hooks welded to its backside on 6-in. centers. These hooks were fully embedded in the concrete during construction to provide good contact between the pressure liner and the concrete surface. On the front surface of the liner, 1-in.-diameter bosses were welded to support the shrapnel-protection plates. Two layers of 12- × 12- × 0.25-in. mild-steel plates were then bolted to the liner using 1/4-in. studs and nuts. The plate edges were staggered between layers and were supported to give a 1/2-in. air gap between layers. Due to the staggering, 1/4 and 1/2 plate sections were used at the edges of the grid to provide the full dynamic mass from a rebound/pullout-resistance standpoint. For each full-size plate, five studs were used. The shrapnel plates were precoated with various high-temperature coatings to evaluate their ease of cleaning and durability from the effects of the explosive fireball.

A single 2.3-ft × 2.75-ft × 2-in. steel plate hinged on a steel framework was used to seal the bullnose opening from the inside of the chamber. The frame, which was welded from 8-in. × 1/2-in. angle, was cast or embedded into the concrete adjacent to the sealing plate. Figure 7 shows this embedment early in the construction process. A simple pipe hinge was constructed between the frame and the sealing plate so that the sealing plate would act as a bullnose door. Six 1-in. × 23-in.-long bolts were passed through the frame from the outside of the chamber into tapped holes in the back surface of the sealing plate to close off the bullnose opening. Figure 11 shows the 1/4-scale chamber model after the forms were removed.

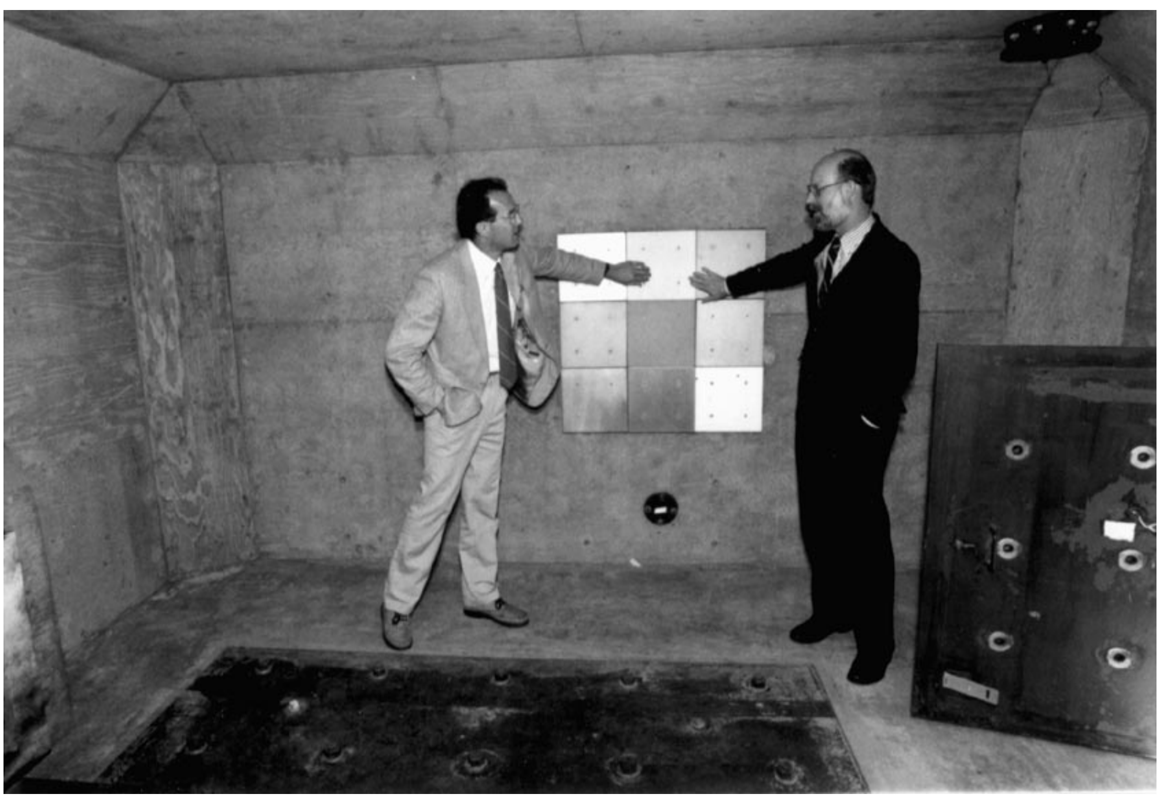


Figure 10. High-temperature coatings on shrapnel protection plates.

Figure 11. 1/4-scale chamber ready for testing.

Experimental Setup

Sixteen blast tests using 0.3 lb (25%) to 2.58 lb (125%) of C4 explosive were performed within the instrumented 1/4-scale chamber model. The charges were all spherical, double, center-detonated, bare high explosive. C4 explosive was used because it was readily available and closely matched the heat of detonation of the operational-limit explosive PBX-9404. For each test, the charge was supported from ceiling hooks by lightweight strings such that the center of the charge was 12 in. above the top surface of the shot anvil. In the 1/4-scale model, the 12-in. elevation represented the FXR beam centerline, where most of the experiments would be conducted. Only two charge locations were used, but they were selected to provide the worst-case loading on the 1/4-scale structure. The first and largest charge location was in CDR Zone 1 near the center of the anvil (see Fig. 12). This represented the maximum operational charge limit of 60 kg of PBX-9404 and thus provided the worst-case global loading on the structure. The second location, with smaller charge amounts, was in CDR Zone 4 near the bullnose (see Fig. 13). This simulated close-in, highly localized loading on the bullnose. Table 2 shows the test matrix.

Closed-door tests were performed at four scaled levels (25%, 50%, 100%, and 125%) of the CFF operational explosive mass limit of 60 kg of PBX-9404. The 125% shots were performed to simulate firing chamber overtesting, as required by Laboratory policy.

Since personnel would not be present in the adjacent parts of the CFF during the qualification testing, the worst-case scenario for an accidental detonation with the door open would be at the normal operational (100%) explosive mass limit. Based on this reasoning, the open-door tests were performed at the 100% level (see Figs. 14 and 15).

For a replica scale model, the amount of explosive mass is scaled geometrically by the cube of the scale factor; i.e., $(1/4)^3 = 1/64$. Thus, 937.5 g of C4 high explosive detonated in the 1/4-scale model would be equivalent to 60 kg of C4 in the full-size chamber.

Access to the interior of the chamber to set up the charges was gained through a 3- $\times$ 3.5-ft opening that represented the large CFF 12- $\times$ 14-ft equipment access door. Since the 1/4-scale model did not contain a built-in ventilation system or any personnel safety system monitors, the model was treated as a confined area. Therefore, portable oxygen sensors were used by shot personnel before entry to verify that sufficient oxygen was present. After each test was fired and the

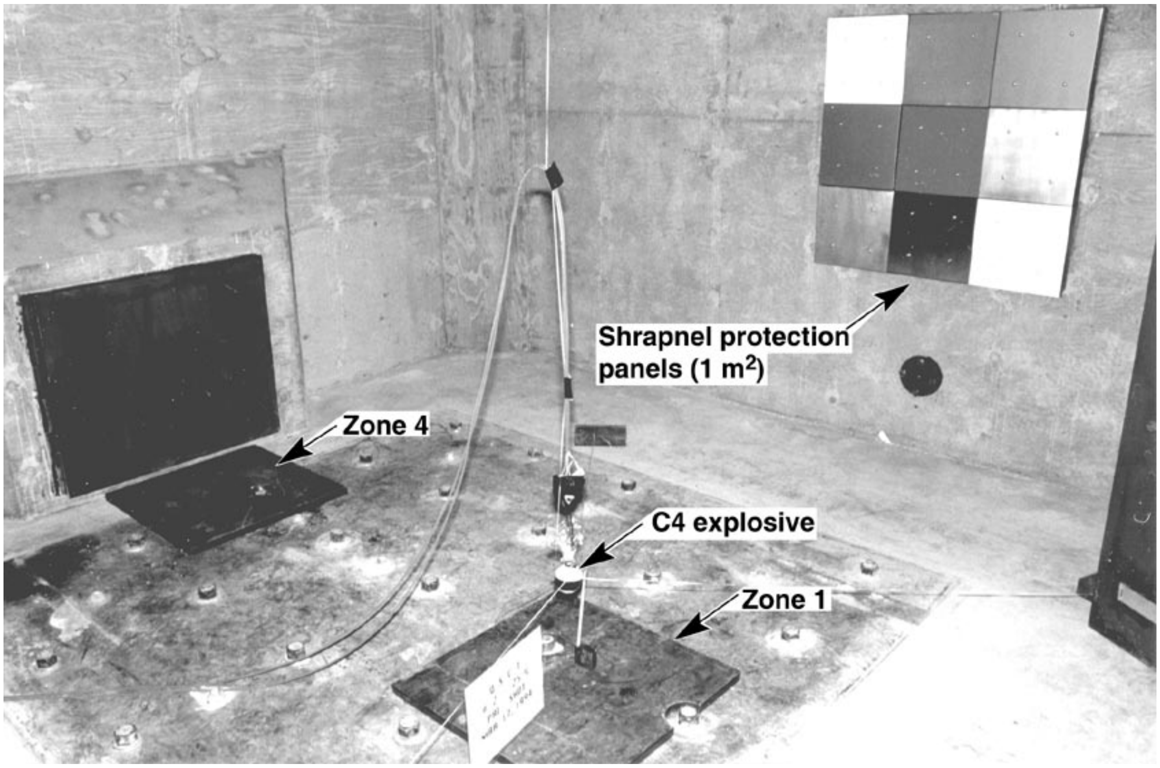


Figure 12. Explosive charge positioned in Zone 1 prior to detonation.

Figure 13. Explosive charge positioned in Zone 4 (near bullnose) prior to detonation.

Table 2. 1/4-scale model testing matrix.[13]

Test # (sequence)	Shot (QSCT-#)	Zone	Door position	Energetic material (lb)	Max. equiv. TNT (lb)	% operational charge weight	Z_{min} (ft/lb$^{1/3}$)
3	1	4	Closed	0.30	0.39	25	1.25
1	2	1	Closed	0.52	0.67	25	1.14
2	3	1	Closed	0.52	0.67	25	1.14
6	4	4	Closed	0.60	0.78	50	1.00
4	5	1	Closed	1.03	1.34	50	0.91
5	6	1	Closed	1.03	1.34	50	0.91
9	7	4	Closed	1.21	1.57	100	0.79
7	8	1	Closed	2.07	2.58	100	0.72
8	9	1	Closed	2.07	2.58	100	0.72
14	10	4	Closed	1.51	1.96	125	0.73
15	11	1	Closed	2.58	3.36	125	0.67
16	12	1	Closed	2.58	3.36	125	0.67
10	13	1	Open	2.07	2.58	100	0.72
11	14	1	Open	2.07	2.58	100	0.72
12	15	1	Open	2.07	2.58	100	0.72
13	16	1	Open	2.07	2.58	100	0.72

Figure 14. Open-door test setup with exterior blast transducers in foreground.

Figure 15. Double fireball recorded with 8-mm video camera during open-door test 15.

interior chamber pressure had returned to ambient, the chamber was cross-ventilated by opening both the bullnose door and the chamber door. Post-detonation gases were purged for 15 minutes by an external portable fan that introduced fresh air via a trunkline positioned into the bullnose opening.

Instrumentation

Instrumentation for the 1/4-scale model consisted of 60 channels of strain gauges, thermocouples, and pressure transducers. Strains were measured in the concrete (see Fig. 16), on the rebar, on the anvil hold-down bolts, and on the bullnose and sealing doors. Five blast and two quasistatic pressure measurements were made at key locations on the inside surfaces of the chamber. For the open-door tests, exterior blast leakage measurements were also made. For the closed-door tests, average interior air temperature was also measured by using ceiling-mounted thermocouples. Locations and model numbers of the instrumentation are shown on drawing AAA-93-103451-0B in Appendix C. Table 3 lists the gauge numbers, locations, and bandwidths of all of the closed-door instrumentation.

For the four open-door tests, six torpedo ballistic-type pressure transducers (SP1-SP6) were mounted 1.5 ft above ground and generally were positioned by aiming the normal to each transducer diaphragm toward the door opening. PCB model 137A11 (SP1) and Model 137A12 (SP2 through SP6) were used to record the pressures at a sampling rate of 100 kHz. External blast pressure was measured at 22 distinct locations and orientations, as shown in Fig. 17.

Prior to the first test, a problem developed with some of the weld-on strain gauges attached to the rebar. Their electrical resistance had increased over a weekend to such an extent that they could not be balanced without changing resistors in the Wheatstone bridge circuit. Eventually over the next 2 months, the resistance of 19 of these gauges continued to increase rapidly toward an infinite resistance condition (open circuit). To obtain strain readings at three important failed gauge locations, replacement foil strain gauges were mounted on the rebar prior to test #7. The replacement gauges were mounted at the center of the ceiling on the inner mat, at a northeast corner wall haunch bar, and on the outer mat of the north wall (S14, S26, S10). Access to the rebar in these areas was gained by

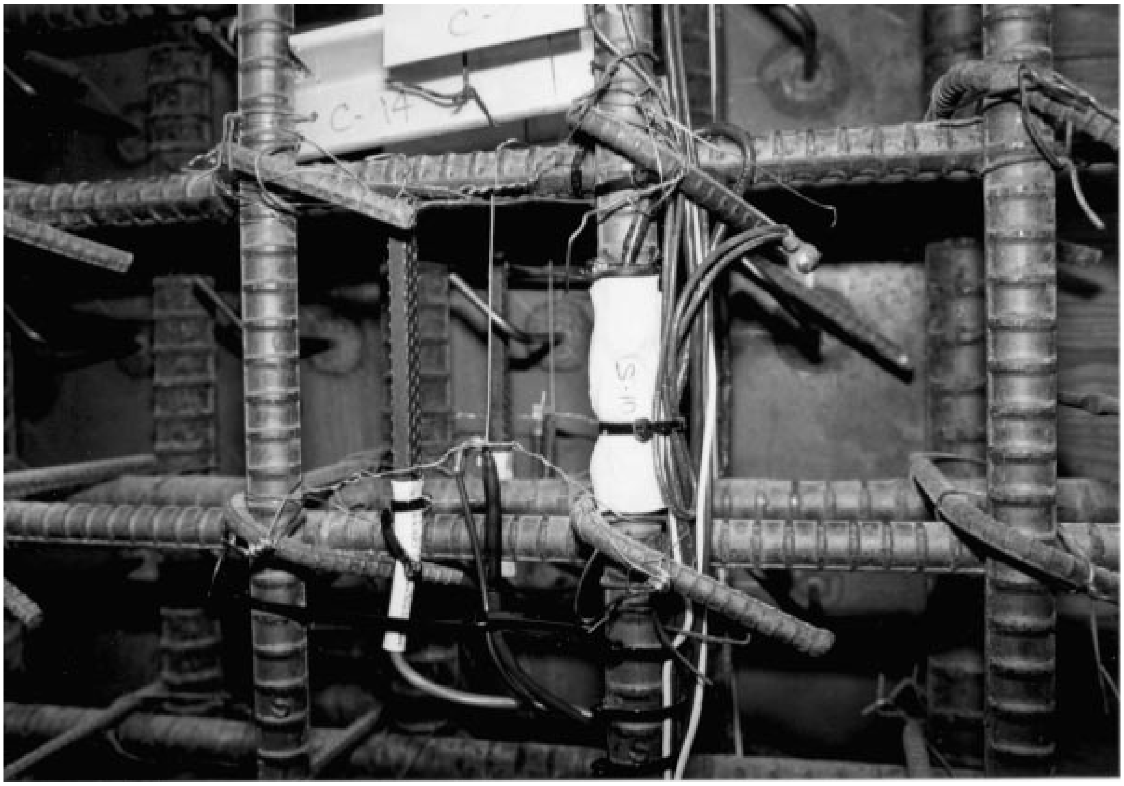


Figure 16. Concrete strain gauges C7 and C14 on the outside of the north wall. Note J hooks on the pressure liner in the background.

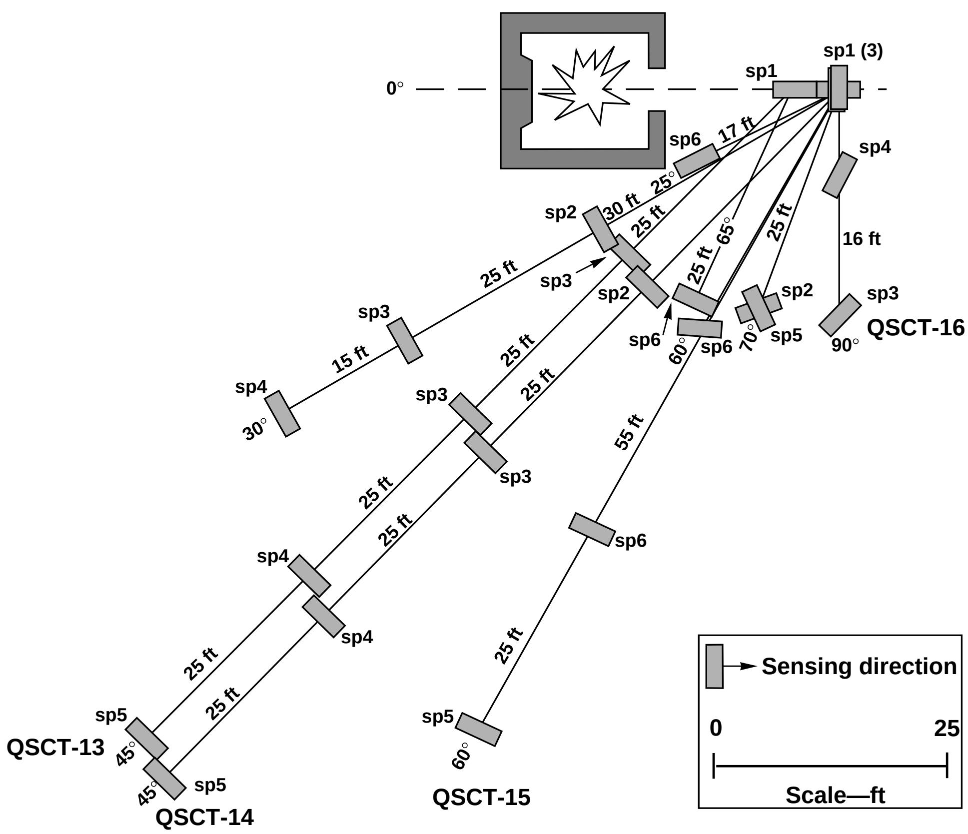


Figure 17. Open-door pressure measurement locations.

Table 3. Closed-door testing instrumentation.

	Gauge No.	Description	Effective band-width (kHz)
	P1	Bullnose blast	
Internal blast	P2	Ceiling blast	
pressure	P3	North wall, zone 1, shot elevation	50
	P4	Door blast	
	P5	South wall midspan	
Internal quasi-	P6	Quasistatic pressure	0.5
static pressure	P7	Quasistatic pressure	
Internal	T1	Ceiling temperature	0.5
temperature	T2	Ceiling temperature	
	C1	Bullnose, E-W, outer	
	C2	Bullnose, E-W, inner	
	C3	Bullnose, N-S, inner	
	C4	Floor bottom, N-S	
	C5	Floor top, N-S	
	C6	Door frame, S corner, outer	
Concrete	C7	N wall, center, vertical, outer	20
strain	C8	N wall, center, vertical, inner	
	C9	N wall, top, vertical, outer	
	C10	Ceiling @ N wall, N-S, outer	
	C11	Ceiling @ center, N-S, upper	
	C12	Ceiling @ center, N-S, lower	
	C13	Floor, N-S, upper	
	C14	N wall, center, E-W, inner	
	C15	N wall, center, E-W, outer	
	S1	Bullnose door, N-S	
	S2	Bullnose, E-W, outer mat	
	S3	Bullnose, N-S, outer mat	
	S4	North wall @ W corner, outer mat	
	S5	North wall @ W corner, inner mat	
	S6	Door, N-S	
	S7	Door trim, S corner, outer	
	S8	Floor, N-S, lower	
	S9	N wall, Zone 1 shot elev. vertical, inner	
	S10	N wall, center, vertical, outer	
	S11	N wall, center, vertical, inner	
	S12	N wall, top, vertical, inner	
	S13	Ceiling @ N wall, N-S, inner	
	S14	Ceiling @ center, N-S, lower	
Steel strain	S15	Ceiling @ center, N-S, upper	20
	S16	Ceiling @ center stirrup	
	S17	Ceiling @ NE corner stirrup	
	S18	Stirrup, N wall top @ ceiling	
	S19	Stirrup, N wall center	
	S20	Stirrup, N wall @ Zone 1 elevation	
	S21	N wall, Zone 1 shot elev., vertical, outer	
	S22	Floor, upper, E-W	
	S23	Stirrup, floor	
	S24	Floor, lower, E-W	
	S25	Ceiling haunch @ center N wall	
	S26	Wall haunch @ center NE corner	
	S27	Stirrup, top of bullnose	
	S28	E wall @ door, vertical, outer	
	S29	Shrapnel plate anchor, N-S	
	S30	Noise gauge (ceiling @ center N wall)	
	S31	Anvil bolt, vertical	

chipping away the concrete cover to a depth of about 1.5 in. thick by 6 in. across. Then the new gauges and their signal wires were sealed against moisture and protected with a 1/4-in.-thick steel plate. No attempt was made to patch the chipped-away concrete. The foil replacement gauges performed flawlessly for the remainder of the tests. Due to budgetary restrictions, the failed gauges were not removed and dissected. The most widely held theory for their failure is corrosion within their stainless-steel jackets.

Empirical Results

From the 16 experiments conducted in the 1/4-scale model, 44 million data points were collected from 880 time-series data records. This data, scaled in engineering units, has been archived in ASCII on an RCD-rom in ISO-9660 format, which is readable by Apple Macintosh computers and PCs. Because the amount of data is so large, only the maximum levels recorded from the 16 tests are presented in this report. For the closed-door tests, maximum tensile and compressive strains have been analyzed and are tabulated in Tables A1 and A2 of Appendix A.

From the maximum measured strains in Tables A1 and A2, the corresponding maximum tensile and compressive stresses have been calculated and are shown in Tables A3 and A4. Material properties listed in Table 4 were used to calculate the maximum stresses from the measured maximum strains. To access and evaluate the original nonyielding criteria, safety factors for tensile and compressive dynamic yielding based on the Table 4 properties were calculated and are listed in Tables A5 andA6. Safety factors less than 1 indicate yielding and are shown in bold for graphical comparison.

Peak external blast pressures from the open-door tests are summarized in Fig. 18. Peak internal blast pressures from each data record are tabulated in Table 5. Typical internal blast pressure traces recorded from the 100% charge levels for the bullnose and the south wall are shown in Figs. 19 and 20, respectively.

Figure 21 shows quasistatic gas pressure and corresponding average air temperature from a 125% over-test in Zone 1. While it was intended to measure only the quasistatic gas pressure, the pressure transducer also was exposed to the more impulsive high-pressure shock waves. This is believed to have excited an internal resonance within the transducer that produced a false overshoot and ringing for the first 10 seconds. The trace in Fig. 21a has been filtered to remove erroneous ringing and overshoot.

Table 4. Material properties and acceptable strain levels.

Category	Elastic modulus (10^6 psi)	Microstrain at dynamic yield: Tensile	Microstrain at dynamic yield: Compressive
Bolts	**30.00**	**1500**	**1500**
Rebar	**29.00**	**2586**	**2586**
Concrete	**4.68**	**125**	**1410**
Doors	**30.00**	**1500**	**1500**

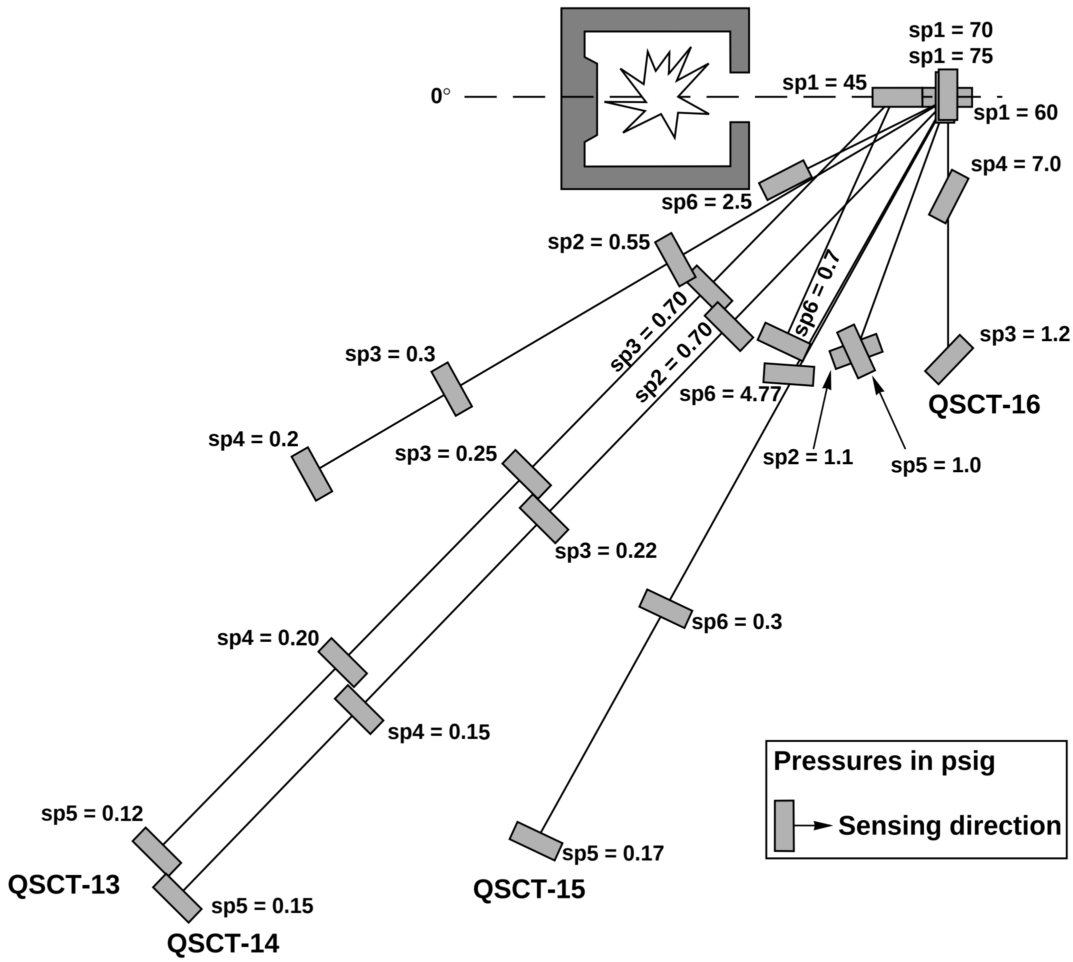


Figure 18. Open-door test pressures map.

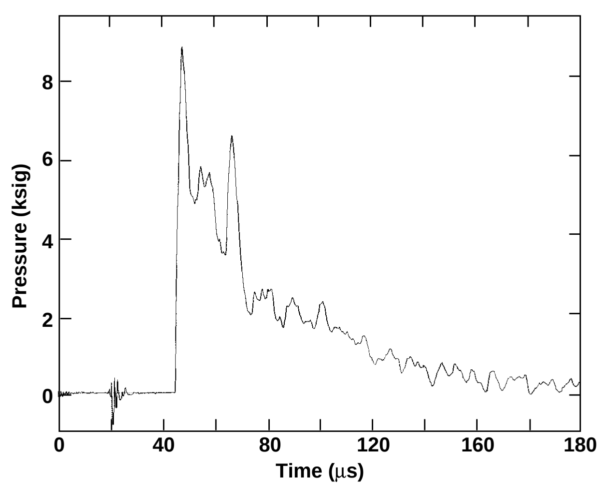


Figure 19. Typical close-in blast pressure trace on bullnose from 100% charge in Zone 4 (test 9).

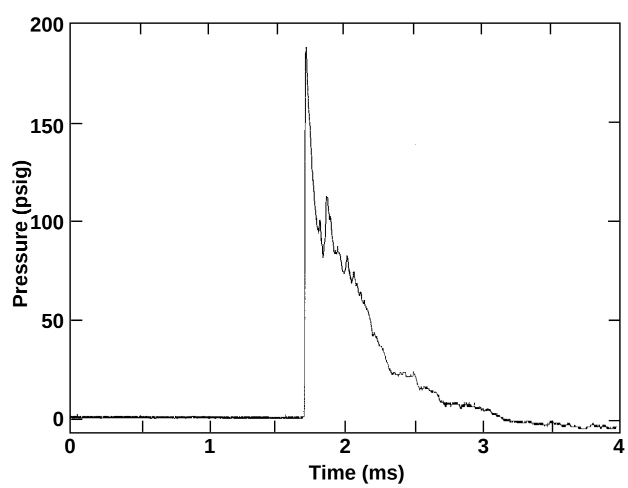


Figure 20. Typical far-range blast pressure trace on south wall from 100% charge in Zone 1 (test 8).

Table 5. Maximum internal blast pressures (psig).

Test No.		1	2	3	4	5	6	7	8	9	14	15	16
Shot series QSCT-		2	3	1	5	6	4	8	9	7	10	11	12
C4 explosive wt (lb)		0.52	0.52	0.3	1.03	1.03	0.6	2.07	2.07	1.21	1.51	2.58	2.58
% of full-scale chg.		25			50			100			125		
Zone		1	1	4	1	1	4	1	1	4	4	1	1
Bullnose	P1	-	-	3612	318	282	1686	550	420	8723	15,322	-	-
Ceiling	P2	-	38	33	-	-	-	77	102	79	94	185	188
North wall, zone 1 shot elev.	P3	-	61	-	211	218	65	1185	305	201	133	445	423
Door	P4	-	64	-	323	707	139	1259	335	100	-	1138	267
South wall, midspan	P5	-	45	15	115	93	51	190	186	76	-	217	230

(-) indicates data not available

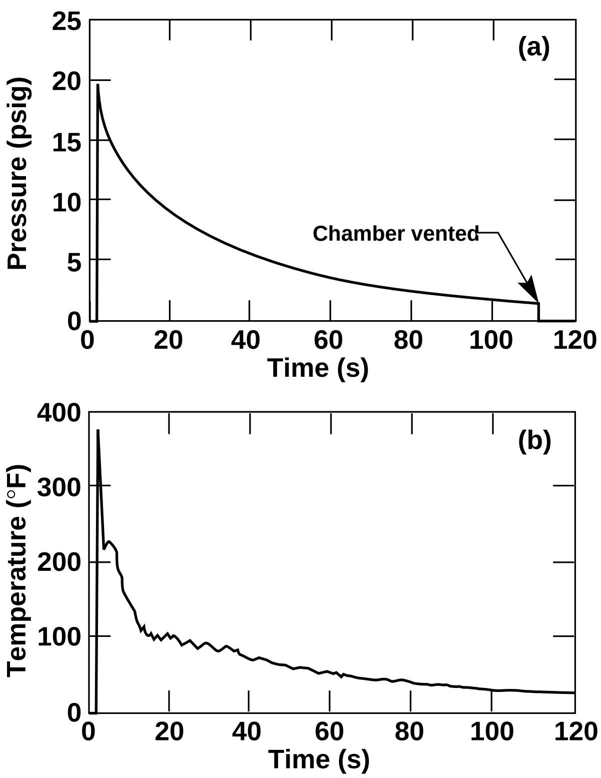


Figure 21. Typical quasistatic gas pressure and temperature records for closed door tests with 125% charges detonated in Zone 1.

Observations and Conclusions

1. From the safety factors for dynamic ***compressive*** yield (see Table A6), no problem is apparent in the steel reinforcement or the concrete as long as the members are in compression. Safety factors calculated from the 100% and 125% testing levels range from 2.6 to 647, the worst case (SF = 2.6) being in the concrete at the center of the ceiling near the inner reinforcing mat (C12).

2. Based on the safety factors for dynamic ***tensile*** yield, no problem is apparent in the steel reinforcement. However, at seven distinct gauge locations within the concrete, the safety factors for dynamic tensile yielding were less than 1.0. This is particularly evident in the data for the 100% and 125% testing levels in Table A5. The implication is that blast-induced cracking of the concrete is likely to initiate in these areas. The areas of concern are the center spans of the north wall and ceiling. Because the firing chamber is symmetrical, the following observations for the north wall also would apply to the south wall.

Specifically, at 100% and 125%, the vertical strain in the north wall outer concrete center span (C7) exceeded dynamic yield four out of six times, giving consistently low safety factors (0.86 to 0.66). For only one experiment out of six did the inner concrete gauge in this same area produce an unacceptable SF of 0.96. In the horizontal direction (east-west), the inner concrete gauge (C14) indicated yielding (SF = 0.93, 0.80) and only for the two Zone-1 experiments at the 100% level. At the 125% level, the safety factors for gauge C14 increased to 1.81 and 1.69 for Zone 1.

Similarly low safety factors (0.84, 0.87) were measured in the upper concrete of the ceiling

(C11) for the two 100% test levels in Zone 1. At the 125% level, the safety factors for the outer concrete had increased to 1.32 and 1.24. This appears to be at the expense of the inner concrete (C12) safety factors, which then deceased to 0.95 and 0.88. From these observations, it is assumed that cracking of the concrete in the ceiling initiated at the outer surface and eventually advanced through the ceiling to the inner surface. To enhance the visual effects of the cracks, the concrete was moistened and photographed during different stages of drying before the 125% shot level. Figures 22–24 show typical cracks from the dynamic response of the firing chamber.

3. Low safety factors for dynamic tensile yielding (SF = 0.71, 0.72) also were recorded on gauge C6, located in the concrete near the corners of the door frame during tests 9 and 15. This observation is assumed to be less important, inasmuch as the details for the extra reinforcement in this region were not fully specified in the CDR, and high localized strains were expected.

4. At the 50% shot level, low tensile safety factors for dynamic yielding (SF = 0.91, 0.97) were recorded in the bottom of the concrete floor. This was consistent with the results from previous testing.[13] When a previously developed blast-attenuation system was used for the remaining 10 experiments above the 50% level, the lowest factor of safety was 2.08 for the 125% level. Figure 25 shows the floor blast attenuation system in place.

5. Based on the measured strain in a single anvil hold-down bolt in Zone 1 (gauge S31), it is recommended that the number of anvil hold-down bolts be increased. It appears that significant rebounding of the anvil occurs, which induces very high tensile forces and yielding in the hold-down bolts. Tensile safety factors as low as 0.27 were measured at the 100% level. Additionally, by adding more bolts and thus decreasing the spacing between bolts, the tensile rebound forces are expected to be spread out more uniformly within the concrete below the anvil. The transfer of these tensile rebound forces into the concrete through an insufficient number of anchor bolts is speculated to cause highly localized yielding, leading to through-thickness cracking, as observed during the floor section testing.[13]

6. As expected from cracked section concrete design, it appears that tensile yielding (i.e., cracking) of the concrete increases the damping of the vibrational response of the

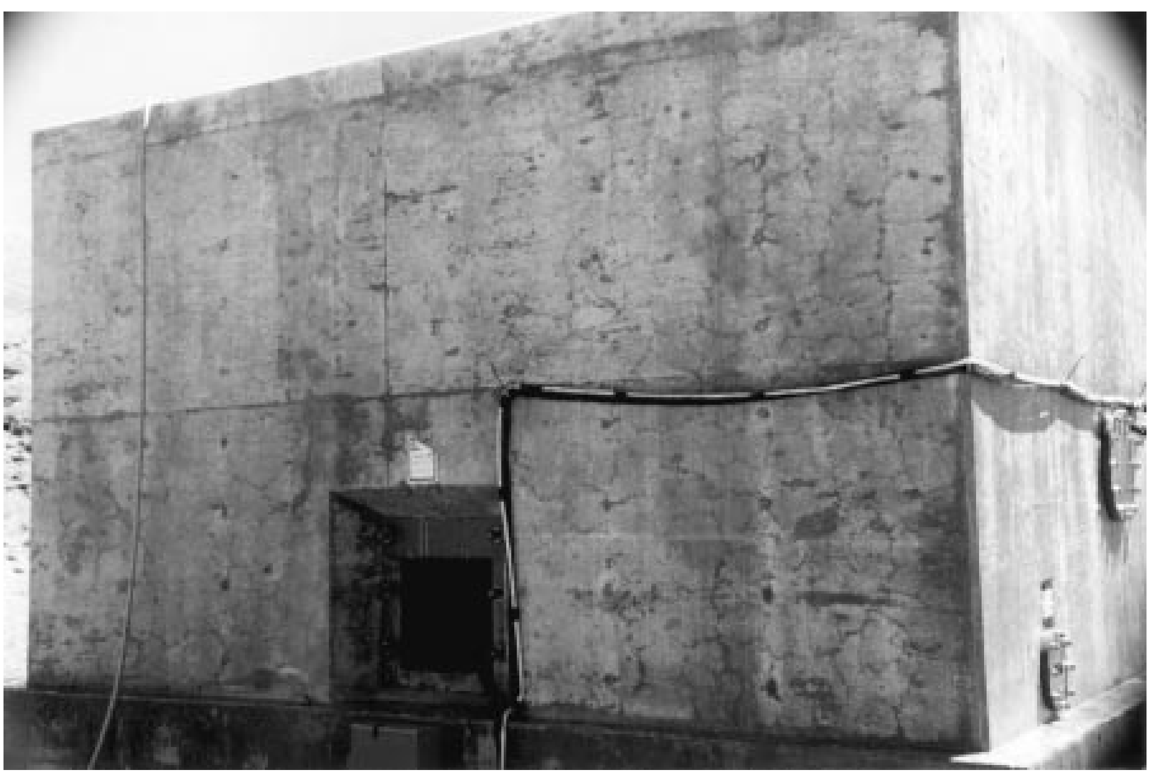


Figure 22. Exterior cracks on bullnose (west) side of chamber after 100% level shots.


Figure 23. Interior cracks in floor between anvil and north wall.

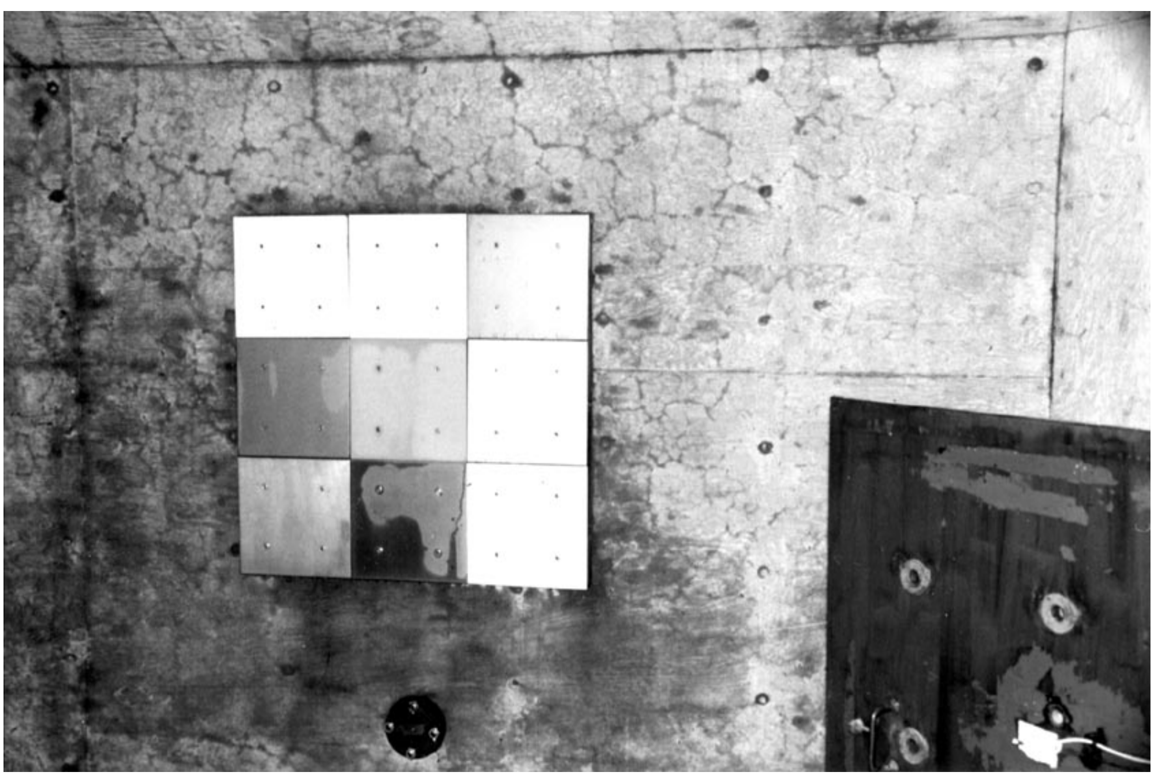


Figure 24. Interior cracks in north wall after 100% charge level experiments.

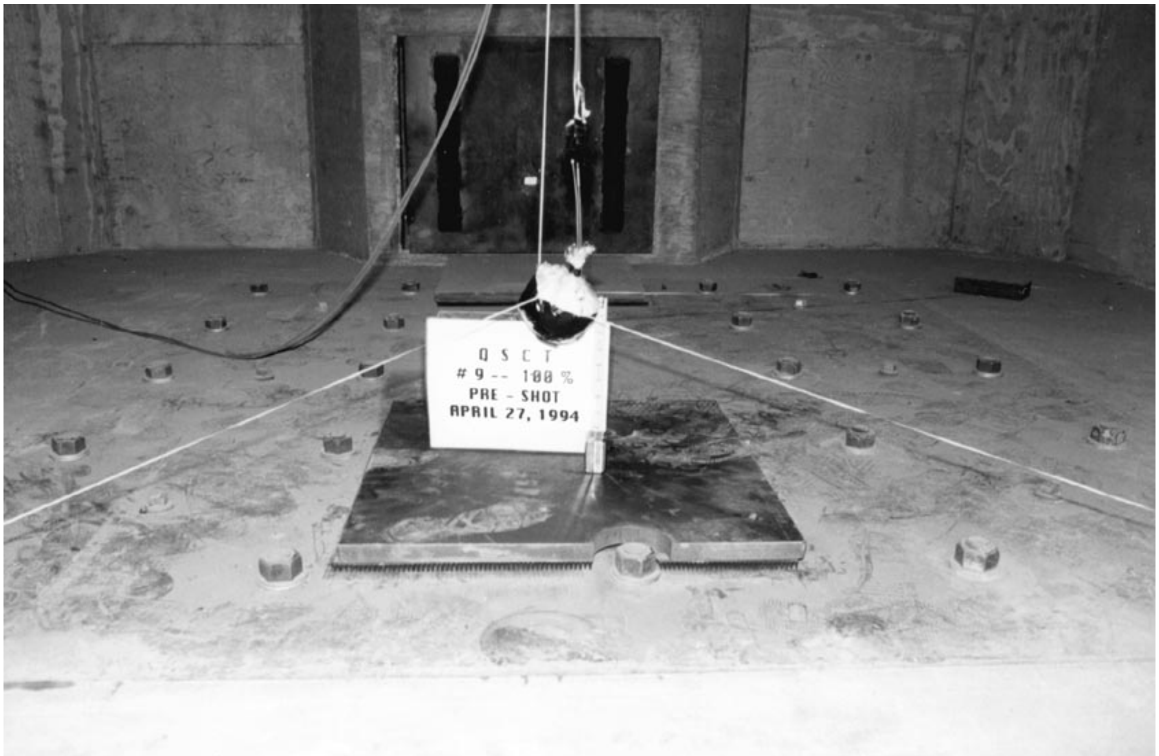


Figure 25. Blast attenuation system between explosive charge and the floor anvil.

structure. This can be seen by examining Fig. 26, which gives a chronological history of the strain in the concrete of the north wall (gauge C7) prior to and during yielding. This figure also gives evidence of strain relaxation and redistribution by the reduction in the peak strain value from (a) to (b) . It is not clear that this cracked section behavior is desirable from a repeated use standpoint, in that it may not be compatible with the original design criteria of an infinite-life elastic response. Clearly, the long-term behavior after cracking has not been tested in these experiments, and further study is recommended.

7. Various high-temperature coatings were applied to the nine mild-steel shrapnel-protection plates mounted within the north inside wall of the chamber. Table 6 lists these coatings by surface preparation and manufacturer's name. These coatings, which were all at a scaled distance of approximatley 4.5 $ft/lb^{1/3}$ from a charge in Zone 1, performed equally well and did not show any signs of burning from the detonation fireball.

High-temperature paint was also applied to the inside surface of the bullnose door, which was located at a scaled distance of 0.73 $ft/lb^{1/3}$ from Zone 4. Because it was close to the charge, the paint showed some signs of ablation and burning.

8. Unexpectedly, about half of the steel rebar strain gauges failed just before and just as testing started. Although this was unfortunate, we overcame this condition by replacing strain gauges during mid-testing and successfully obtained rebar strain at important points (see Fig. 27). Since similar strain gauges are planned to be used in the full-size chamber to monitor its dynamic response over its lifetime, it is recommended that these failures be investigated to determine the exact cause so that they may be prevented in the future.

9. The measured peak internal blast pressures were compared with those calculated by using the SHOCK[14] computer program at the 100% shot level for detonations in Zones 1 and 4. The SHOCK computer program was the program used in the CDR to calculate the load pressures and impulses for the design of the chamber. For comparison, Table 7 compares measured and predicted. For close-in loading at scaled distances less than 1.0 $ft/lb^{1/3}$, the measurements are close to those predicted (~85%). In the far

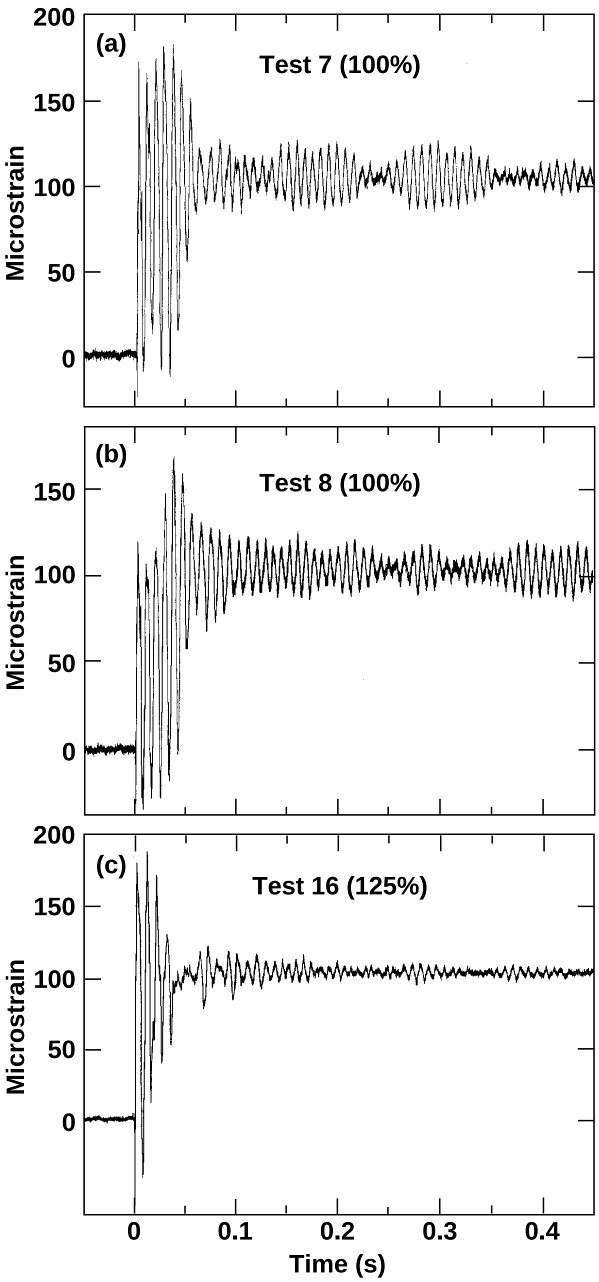


Figure 26. Damping increased, possibly because of cracking in the concrete in the north wall of the chamber (gauge C7).

Table 6. High-temperature coatings used on shrapnel protection plates.

1. Degreased, Rust Knock Out primer, white Break-Through latex enamel
2. Sandblasted, Brinner 565 undercoat only
3. Sandblasted, Steelit 2203 undercoat, Steelit Anti-Rust stainless-steel coating
4. Degreased, Steelit 2203 undercoat, Steelit Anti-Rust stainless-steel coating
5. Sandblasted, metallic ceramic coating
6. Sandblasted, Northwestern Industries #2
7. Sandblasted, Northwestern Industries #1
8. Sandblasted, copper plated, bright nickel plating
9. Degreased, white Break-Through enamel

range loading regime, the measurements are, on average, 2.8 times higher than those predicted by SHOCK. The most likely explanation for this large discrepancy is the use of electrician's tape over the face of the pressure sensing diaphragm to eliminate the temperature effects from the fireball. In doing so, the presence of the tape may have mass-loaded the sensor and thus changed its effective calibration.

10. Figure 28 shows a reasonable correlation of the peak values for measured quasistatic pressure and temperature as a function of charge weight. As expected, the quasistatic pressure is due to the hot products of combustion and it decreases at the same rate as the gases cool (see Fig. 21).

11. The quasistatic gas pressure measured during the experiments tracked the predicted pressures fairly well. Figure 29 is a plot of the peak values of the quasistatic pressures as a function of the charge weights used. At the 125% shot level, the measured pressure was 18 psig vs 21 psig calculated via the Weibell formula.

Table 7. Comparison of measured and predicted internal blast pressures for 100% full-scale charge.

		Measured data* (psig)		SHOCK program prediction (psig)		Measured ÷ predicted	
		Shot zone		Shot zone		Shot zone	
Location	Gauge	1	4	1	4	1	4
Bullnose	P1	420	8723	138	10,258	3.04	0.85
Ceiling	P2	102	79	124	34	0.82	2.32
North wall, zone 1 shot elev.	P3	305	201	138	41	2.21	4.93
Door	P4	335	100	136	21	2.46	4.67
South wall, midspan	P5	186	76	56	39	3.31	1.93

*Measured data from tests 8 and 9.

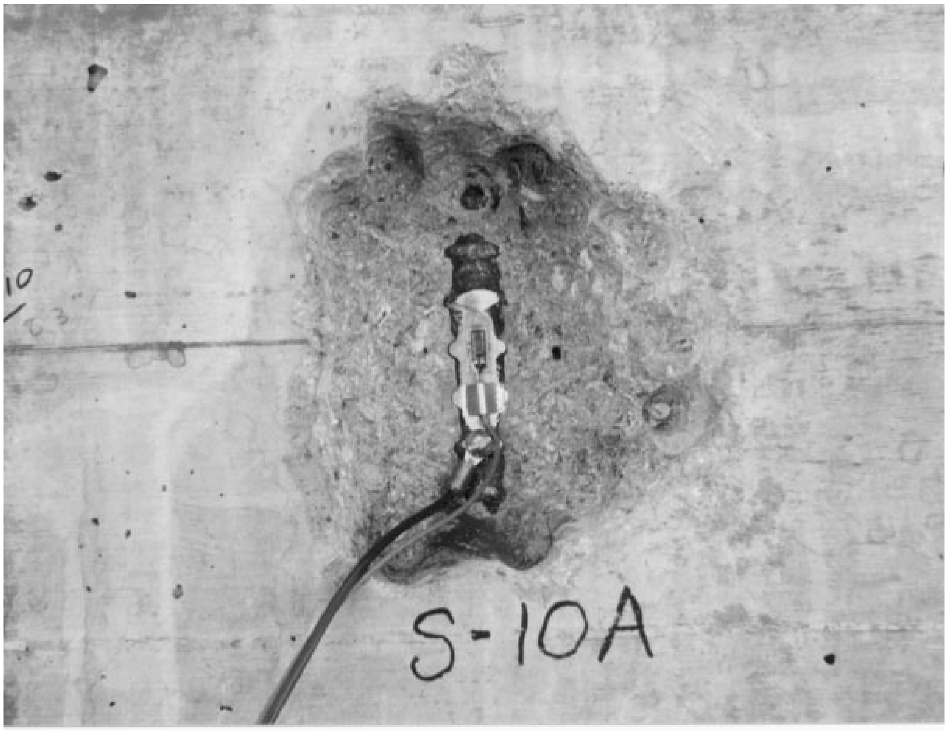


Figure 27. Replacement strain gauge added to rebar after concrete was cured.

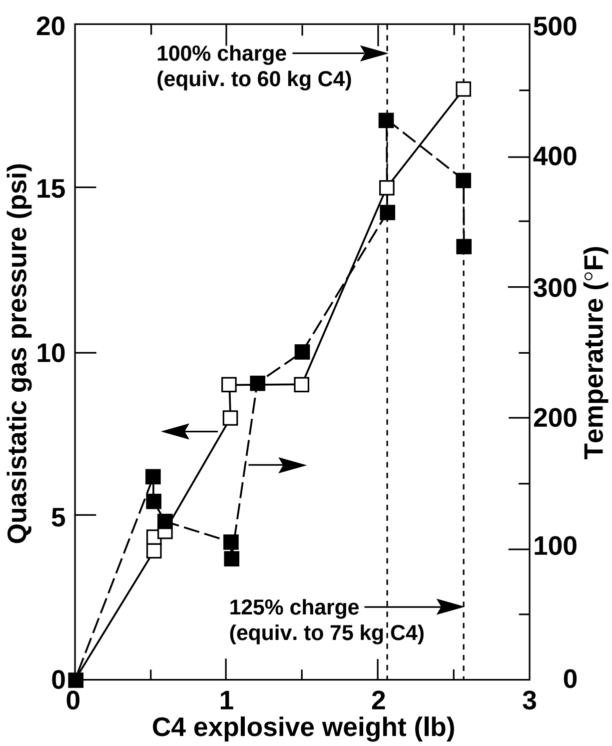


Figure 28. Correlation between peak quasistatic pressure and temperature for the 1/4-scale model as a function of charge weight.

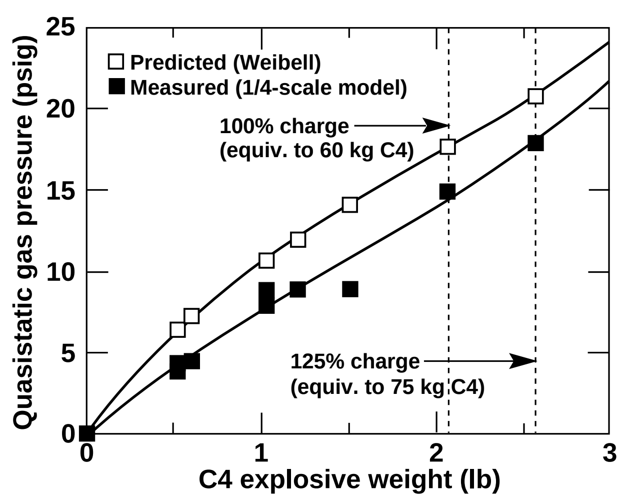


Figure 29. Comparison of predicted and measured quasistatic gas pressure for the 1/4-scale model as a function of charge weight.

Notes and References

1. The design of this facility is governed by DOE requirements and regulations found in DOE 5481.1B, DOE 5430.1A, DOE 6430.1A, DOE / AD-0006 / 1, DOE / EV-0043, DOE / EV-06194 (*DOE Explosives Safety Manual*), DOE / NEPA, and 10CFR Part 435 (*Energy Conservation Report*).
2. Composition of HMX: octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine.
3. *Structures to Resist the Effects of Accidental Explosions*, Joint Departments of the Army, the Navy, and the Air Force, TM5-1300 / NAVFAC P-397 / AFR 88-22 (Nov. 1990).
4. *Site 300 Contained Firing Facilities—Conceptual Design Report*, U.S. Department of Energy Project Number 94-SAN-LLN-02, prepared by Holmes & Narver Architects-Engineers, Sept. 1992.
5. J. W. Pastrnak, C. F. Baker, and L. F. Simmons, *Shrapnel Protection Testing in Support of the Proposed Site 300 Contained Firing Facility*, Lawrence Livermore National Laboratory, UCRL-ID-110732 (1992).
6. J. W. Pastrnak, C. F. Baker, and L. F. Simmons, *Quarter Scale Close-in Blast Loading Experiments in Support of the Planned Contained Firing Facility*, Lawrence Livermore National Laboratory, UCRL-JC-116822 (1994).
7. *Health & Safety Manual*, Lawrence Livermore National Laboratory, Livermore, CA, M-010 (1990), Ch. 6.26.
8. The High-Explosives Applications Facility can detonate up to 10 kg of high explosive in stainless-steel firing vessels.
9. *Soils Inspection Report*, Consolidated Engineering Laboratories, Pleasanton, CA, PFN # 812-93001 (1992).
10. *Moisture Density Relations Test Report*, Consolidated Engineering Laboratories, Pleasanton, CA, PFN # 812-93001 (1992).
11. *Concrete Compression Test Data*, Consolidated Engineering Laboratories, Pleasanton, CA, PFN #93004 (1-18-94) and (2-4-94).
12. Burke Metallic Spec. Grout, 9500 psi compressive strength, Burke Products Inc., San Mateo, CA.
13. J. W. Pastrnak, 1 / 4 Scale Model Project Plan (1993).
14. SHOCK Users Manual, Naval Civil Engineering Laboratory, Port Hueneme, CA, Version 1.0 (1988).

Appendix A Tabular Strain Data

Table A1. Maximum tensile strains (μin./in.).

Test No.:		1	2	3	4	5	6	7	8	9	14	15	16
Test series (QSCT):		2	3	1	5	6	4	8	9	7	10	11	11
C4 explosive weight (lb):		0.52	0.52	0.3	1.03	1.03	0.6	2.07	2.07	1.21	1.51	2.58	2.58
% of full-scale charge (zone):		25 (1)	25 (1)	25 (4)	50 (1)	50 (1)	50 (4)	100 (1)	100 (1)	100 (4)	125 (4)	125 (1)	125 (1)
Test date (1994):		3/18	4/5	4/5	4/12	4/12	4/12	4/27	4/27	4/27	6/7	6/7	6/8
Gauge													
C1	Bullnose, E-W, outer	5	5	16	17	11	20	8	5	24	33	5	6
C2	Bullnose, E-W, inner	6	6	11	20	24	17	15	14	28	30	16	16
C3	Bullnose, N-S, inner	7.5	8	15	45	43	30	22	20	40	31	21	17
C4	Floor bottom, N-S	0	27	12	138	129	22	52	47	19	42	60	50
C5	Floor top, N-S	90	67	11	194	117	18	24	31	11	32	23	27
C6	Door frame, S corner, outer	0	49	32	65	65	63	96	103	176	110	174	123
C7	N wall, center, vertical, outer	59	67	36	80	82	60	184	171	121	145	120	188
C8	N wall, center, vertical, inner	25	29	21	33	33	39	55	61	130	75	21	88
C9	N wall, top, vertical, outer	20	15	9	16	19	17	13	9	39	25	16	14
C10	Ceiling @ N wall, N-S, outer	8	13	6	12	14	7	12	9	41	19	16	18
C11	Ceiling @ center, N-S, upper	58	68	38	96	101	49	148	143	76	71	95	101
C12	Ceiling @ center, N-S, lower	30	32	50	36	36	92	43	43	84	39	131	142
C13	Floor, N-S, upper	45	20	5	121	85	10	13	5	7	12	16	13
C14	N wall, center, E-W, inner	58	66	36	78	79	55	134	156	103	47	69	74
C15	N wall, center, E-W, outer	15	19	14	22	23	28	39	84	86	49	52	58
S1	Bullnose door, N-S	20	16	112	28	38	206	51	57	282	323	88	54
S2	Bullnose, E-W, outer mat	10	14	41	22	24	58	40	31	89	86	39	25
S3	Bullnose, N-S, outer mat	0	0	0	0	0	0	0	0	0	0	0	0
S4	N wall @ W corner, outer mat	22	26	17	38	34	37	57	63	52	48	72	82
S5	N wall @ W corner, inner mat	0	0	0	0	0	0	0	0	0	0	0	0
S6	Door, N-S	135	130	153	0	0	0	361	320	211	342	431	430
S7	Door trim, S corner, outer	38	38	26	63	61	63	127	150	171	226	44	216
S8	Floor, N-S, lower	35	0	0	0	0	0	0	0	0	0	0	0
S9	N wall, Zone 1 shot elev., vert., inner	0	0	0	0	0	0	0	0	0	0	0	0
S10	N wall, center, vertical, outer	65	0	0	0	0	0	312	330	274	359	442	546
S11	N wall, center, vertical, inner	20	26	18	29	32	37	53	62	59	0	39	39
S12	N wall, top, vertical, inner	45	0	0	0	0	0	0	0	0	0	0	0
S13	Ceiling @ N wall, N-S, inner	90	101	74	146	148	117	336	367	225	266	289	362
S14	Ceiling @ center, N-S, lower	30	0	0	0	0	0	11	12	46	36	41	53
S15	Ceiling @ center, N-S, upper	70	75	75	0	0	0	218	284	0	0	351	343
S16	Ceiling @ center stirrup	2	3	3	4	4	4	0	0	0	9	7	6
S17	Ceiling @ NE corner stirrup	15	1074	939	35	20	20	0	0	0	0	36	44
S18	Stirrup, N wall top @ ceiling	3	8	5	10	20	10	16	22	8	7	18	23
S19	Stirrup, N wall center	0	3	4	6	6	4	7	12	9	13	18	19
S20	Stirrup, N wall @ Zone 1 elevation	7	0	4	9	8	6	14	13	11	13	10	11
S21	N wall, Zone 1 shot elev., vert, outer	30	32	21	46	48	31	100	101	71	99	118	148
S22	Floor, upper, E-W	0	0	0	0	0	0	0	0	0	0	0	0
S23	Stirrup, floor	40	33	0	0	101	0	23	22	0	7	3	3
S24	Floor, lower, E-W	30	20	19	33	37	25	44	42	42	0	0	0
S25	Ceiling haunch @ center N wall	40	40	33	71	65	50	100	99	76	89	106	0
S26	Wall haunch @ center NE corner	0	0	0	0	0	0	131	162	125	117	169	146
S27	Stirrup, top of bullnose	7	9	9	18	14	15	10	10	23	28	21	22
S28	E wall @ door, vertical, outer	0	0	0	0	0	0	0	0	0	0	0	0
S29	Shrapnel plate anchor, N-S	225	288	139	482	485	303	614	500	0	0	0	0
S30	Noise gauge (ceiling @ center N wall)	5	0	0	0	0	0	17	36	21	55	0	0
S31	Anvil bolt, vertical	0	1181	0	0	0	0	7136	7139	7301	0	0	0

Table A2. Maximum compressive strains (μin./in.).

Test No.:		1	2	3	4	5	6	7	8	9	14	15	16
Test series (QSCT):		2	3	1	5	6	4	8	9	7	10	11	11
C4 explosive weight (lb):		0.52	0.52	0.3	1.03	1.03	0.6	2.07	2.07	1.21	1.51	2.58	2.58
% of full-scale charge (zone):		25 (1)	25 (1)	25 (4)	50 (1)	50 (1)	50 (4)	100 (1)	100 (1)	100 (4)	125 (4)	125 (1)	125 (1)
Test date (1994):		3/18	4/5	4/5	4/12	4/12	4/12	4/27	4/27	4/27	6/7	6/7	6/8
Gauge													
C1	Bullnose, E-W, outer	3	9	36	44	43	62	27	22	93	75	18	18
C2	Bullnose, E-W, inner	6	8	19	49	41	43	23	23	50	55	41	41
C3	Bullnose, N-S, inner	6	7	13	32	33	18	21	24	32	20	18	20
C4	Floor bottom, N-S	0	10	11	35	40	15	14	16	9	12	4	8
C5	Floor top, N-S	25	39	13	109	60	22	36	35	15	25	16	40
C6	Door frame, S corner, outer	0	27	20	21	25	34	40	51	50	25	70	85
C7	N wall, center, vertical, outer	37	34	30	40	38	35	27	35	72	47	5	61
C8	N wall, center, vertical, inner	30	35	21	37	41	36	77	69	119	49	133	74
C9	N wall, top, vertical, outer	32	35	24	57	58	47	90	93	142	77	103	110
C10	Ceiling @ N wall, N-S, outer	14	19	11	25	24	18	31	35	55	28	44	57
C11	Ceiling @ center, N-S, upper	18	21	15	20	21	12	5	5	24	16	8	6
C12	Ceiling @ center, N-S, lower	75	108	70	151	171	119	252	277	226	315	477	534
C13	Floor, N-S, upper	20	21	6	63	69	9	21	13	8	19	30	27
C14	N wall, center, E-W, inner	38	35	31	39	35	35	34	48	66	29	31	29
C15	N wall, center, E-W, outer	15	21	13	23	26	24	43	74	73	34	29	45
S1	Bullnose door, N-S	15	13	83	21	22	156	51	31	457	396	112	74
S2	Bullnose, E-W, outer mat	6	16	58	23	22	100	44	35	138	137	25	29
S3	Bullnose, N-S, outer mat	0	0	0	0	0	0	0	0	0	0	0	0
S4	North wall @ W corner, outer mat	14	14	11	19	18	23	23	38	35	31	41	42
S5	North wall @ W corner, inner mat	0	0	0	0	0	0	0	0	0	0	0	0
S6	Door, N-S	135	90	146	0	0	0	121	120	118	160	165	182
S7	Door trim, S corner, outer	18	12	20	17	17	22	34	43	24	26	56	59
S8	Floor, N-S, lower	12	0	0	0	0	0	0	0	0	0	0	0
S9	N wall, Zone 1 shot elev., vert., inner	0	0	0	0	0	0	0	0	0	0	0	0
S10	N wall, center, vertical, outer	38	0	0	0	0	0	79	62	88	94	169	80
S11	N wall, center, vertical, inner	30	40	24	39	42	37	86	81	67	0	25	25
S12	N wall, top, vertical, inner	25	0	0	0	0	0	0	0	0	0	0	0
S13	Ceiling @ N wall, N-S, inner	50	55	39	57	59	45	72	10	82	41	164	7
S14	Ceiling @ center, N-S, lower	41	0	0	0	0	0	141	157	106	136	216	236
S15	Ceiling @ center, N-S, upper	20	22	22	0	0	0	4	28	0	0	32	53
S16	Ceiling @ center stirrup	10	16	7	23	25	11	0	0	0	35	60	68
S17	Ceiling @ NE corner stirrup	7	176	1824	11	0	0	0	0	0	0	13	7
S18	Stirrup, N wall top @ ceiling	5	5	6	14	79	11	12	13	13	12	15	17
S19	Stirrup, N wall center	0	7	6	14	14	10	36	31	11	12	37	38
S20	Stirrup, N wall @ Zone 1 elevation	8	0	7	23	22	13	40	34	24	25	47	46
S21	N wall, Zone 1 shot elev., vert., outer	15	20	11	31	31	18	50	59	20	33	37	34
S22	Floor, upper, E-W	0	0	0	0	0	0	0	0	0	0	0	0
S23	Stirrup, floor	175	135	0	0	392	0	65	61	0	22	81	67
S24	Floor, lower, E-W	10	13	10	19	19	14	12	12	27	0	0	0
S25	Ceiling haunch @ center N wall	25	23	18	25	23	21	33	26	31	25	33	0
S26	Wall haunch @ center NE corner	0	0	0	0	0	0	75	73	70	33	39	42
S27	Stirrup, top of bullnose	10	11	19	21	23	34	33	32	38	46	48	51
S28	E wall @ door, vertical, outer	0	0	0	0	0	0	0	0	0	0	0	0
S29	Shrapnel plate anchor, N-S	35	185	100	238	272	128	327	300	0	0	0	0
S30	Noise gauge (ceiling @ center N wall)	5	0	0	0	0	0	17	20	23	55	0	0
S31	Anvil bolt, vertical	0	248	0	0	0	0	334	590	440	0	0	0

Table A3. Maximum tensile stresses (psi).

Test No.:		1	2	3	4	5	6	7	8	9	14	15	16
Test series (QSCT):		2	3	1	5	6	4	8	9	7	10	11	11
C4 explosive weight (lb):		0.52	0.52	0.3	1.03	1.03	0.6	2.07	2.07	1.21	1.51	2.58	2.58
% of full-scale charge (zone):		25 (1)	25 (1)	25 (4)	50 (1)	50 (1)	50 (4)	100 (1)	100 (1)	100 (4)	125 (4)	125 (1)	125 (1)
Test date (1994):		3/18	4/5	4/5	4/12	4/12	4/12	4/27	4/27	4/27	6/7	6/7	6/8
Gauge													
C1	Bullnose, EW, outer	23	23	75	80	51	94	37	23	112	154	23	28
C2	Bullnose, EW, inner	28	28	51	94	112	80	70	66	131	140	75	75
C3	Bullnose, NS, inner	35	37	70	211	201	140	103	94	187	145	98	80
C4	Floor bottom, NS	0	126	56	646	604	103	243	220	89	197	281	234
C5	Floor top, NS	421	314	51	908	548	84	112	145	51	150	108	126
C6	Door frame, S corner, outer	0	229	150	304	304	295	449	482	824	515	814	576
C7	N wall, center, vertical, outer	276	314	168	374	384	281	861	800	566	679	562	880
C8	N wall, center, vertical, inner	117	136	98	154	154	183	257	285	608	351	98	412
C9	N wall, top, vertical, outer	94	70	42	75	89	80	61	42	183	117	75	66
C10	Ceiling @ N wall, NS, outer	37	61	28	56	66	33	56	42	192	89	75	84
C11	Ceiling @ center, NS, upper	271	318	178	459	473	229	693	669	356	332	445	473
C12	Ceiling @ center, NS, lower	140	150	234	168	168	431	201	201	393	183	613	665
C13	Floor, NS, upper	211	94	23	566	398	47	61	23	33	56	75	61
C14	N wall, center, EW, inner	271	309	168	365	370	257	627	730	482	220	323	346
C15	N wall, center, EW, outer	70	89	66	103	108	131	183	393	402	229	243	271
S1	Bullnose door, NS	94	75	524	131	178	964	239	267	1320	1512	412	253
S2	Bullnose, EW, outer mat	47	66	192	103	112	271	187	145	417	402	183	117
S3	Bullnose, NS, outer mat	0	0	0	0	0	0	0	0	0	0	0	0
S4	North wall @ W corner, outer mat	103	122	80	178	159	173	267	295	243	225	337	384
S5	North wall @ W corner, inner mat	0	0	0	0	0	0	0	0	0	0	0	0
S6	Door, NS	632	608	716	0	0	0	1689	1498	987	1601	2017	2012
S7	Door trim, S corner, outer	178	178	122	295	285	295	594	702	800	1058	206	1011
S8	Floor, NS, lower	164	0	0	0	0	0	0	0	0	0	0	0
S9	N wall, Zone 1 shot elev., vert., inner	0	0	0	0	0	0	0	0	0	0	0	0
S10	N wall, center, vertical, outer	304	0	0	0	0	0	1460	1544	1282	1680	2069	2555
S11	N wall, center, vertical, inner	94	122	84	136	150	173	248	290	276	0	183	183
S12	N wall, top, vertical, inner	211	0	0	0	0	0	0	0	0	0	0	0
S13	Ceiling @ N wall, NS, inner	421	473	346	683	693	548	1572	1718	1053	1245	1353	1694
S14	Ceiling @ center, NS, lower	140	0	0	0	0	0	51	56	215	168	192	248
S15	Ceiling @ center, NS, upper	328	351	351	0	0	0	1020	1329	0	0	1643	1605
S16	Ceiling @ center stirrup	9	14	14	19	19	19	0	0	0	42	33	28
S17	Ceiling @ NE corner stirrup	70	5026	4395	164	94	94	0	0	0	0	168	206
S18	Stirrup, N wall top @ ceiling	14	37	23	47	94	47	75	103	37	33	84	108
S19	Stirrup, N wall center	0	14	19	28	28	19	33	56	42	61	84	89
S20	Stirrup, N wall @ Zone 1 elevation	33	0	19	42	37	28	66	61	51	61	47	51
S21	N wall, Zone 1 shot elev., vert., outer	140	150	98	215	225	145	468	473	332	463	552	693
S22	Floor, upper, EW	0	0	0	0	0	0	0	0	0	0	0	0
S23	Stirrup, floor	187	154	0	0	473	0	108	103	0	33	14	14
S24	Floor, lower, EW	140	94	89	154	173	117	206	197	197	0	0	0
S25	Ceiling haunch @ center N wall	187	187	154	332	304	234	468	463	356	417	496	0
S26	Wall haunch @ center NE corner	0	0	0	0	0	0	613	758	585	548	791	683
S27	Stirrup, top of bullnose	33	42	42	84	66	70	47	47	108	131	98	103
S28	E wall @ door, vertical, outer	0	0	0	0	0	0	0	0	0	0	0	0
S29	Shrapnel plate anchor, NS	1053	1348	651	2256	2270	1418	2874	2340	0	0	0	0
S30	Noise gauge (ceiling @ center N wall)	23	0	0	0	0	0	80	168	98	257	0	0
S31	Anvil bolt, vertical	0	5527	0	0	0	0	33,396	33,411	34,169	0	0	0

Table A4. Maximum compressive stresses (psi).

Test No.:		1	2	3	4	5	6	7	8	9	14	15	16
Test series (QSCT):		2	3	1	5	6	4	8	9	7	10	11	11
C4 explosive weight (lb):		0.52	0.52	0.3	1.03	1.03	0.6	2.07	2.07	1.21	1.51	2.58	2.58
% of full-scale charge (zone):		25 (1)	25 (1)	25 (4)	50 (1)	50 (1)	50 (4)	100 (1)	100 (1)	100 (4)	125 (4)	125 (1)	125 (1)
Test date (1994):		3 / 18	4 / 5	4 / 5	4 / 12	4 / 12	4 / 12	4 / 27	4 / 27	4 / 27	6 / 7	6 / 7	6 / 8
Gauge													
C1	Bullnose, EW, outer	14	42	168	206	201	290	126	103	435	351	84	84
C2	Bullnose, EW, inner	28	37	89	229	192	201	108	108	234	257	192	192
C3	Bullnose, NS, inner	28	33	61	150	154	84	98	112	150	94	84	94
C4	Floor bottom, NS	0	47	51	164	187	70	66	75	42	56	19	37
C5	Floor top, NS	117	183	61	510	281	103	168	164	70	117	75	187
C6	Door frame, S corner, outer	0	126	94	98	117	159	187	239	234	117	328	398
C7	N wall, center, vertical, outer	173	159	140	187	178	164	126	164	337	220	23	285
C8	N wall, center, vertical, inner	140	164	98	173	192	168	360	323	557	229	622	346
C9	N wall, top, vertical, outer	150	164	112	267	271	220	421	435	665	360	482	515
C10	Ceiling @ N wall, NS, outer	66	89	51	117	112	84	145	164	257	131	206	267
C11	Ceiling @ center, NS, upper	84	98	70	94	98	56	23	23	112	75	37	28
C12	Ceiling @ center, NS, lower	351	505	328	707	800	557	1179	1296	1058	1474	2232	2499
C13	Floor, NS, upper	94	98	28	295	323	42	98	61	37	89	140	126
C14	N wall, center, EW, inner	178	164	145	183	164	164	159	225	309	136	145	136
C15	N wall, center, EW, outer	70	98	61	108	122	112	201	346	342	159	136	211
S1	Bullnose door, NS	70	61	388	98	103	730	239	145	2139	1853	524	346
S2	Bullnose, EW, outer mat	28	75	271	108	103	468	206	164	646	641	117	136
S3	Bullnose, NS, outer mat	0	0	0	0	0	0	0	0	0	0	0	0
S4	North wall @ W corner, outer mat	66	66	51	89	84	108	108	178	164	145	192	197
S5	North wall @ W corner, inner mat	0	0	0	0	0	0	0	0	0	0	0	0
S6	Door, NS	632	421	683	0	0	0	566	562	552	749	772	852
S7	Door trim, S corner, outer	84	56	94	80	80	103	159	201	112	122	262	276
S8	Floor, NS, lower	56	0	0	0	0	0	0	0	0	0	0	0
S9	N wall, Zone 1 shot elev., vert., inner	0	0	0	0	0	0	0	0	0	0	0	0
S10	N wall, center, vertical, outer	178	0	0	0	0	0	370	290	412	440	791	374
S11	N wall, center, vertical, inner	140	187	112	183	197	173	402	379	314	0	117	117
S12	N wall, top, vertical, inner	117	0	0	0	0	0	0	0	0	0	0	0
S13	Ceiling @ N wall, NS, inner	234	257	183	267	276	211	337	47	384	192	768	33
S14	Ceiling @ center, NS, lower	192	0	0	0	0	0	660	735	496	636	1,011	1,104
S15	Ceiling @ center, NS, upper	94	103	103	0	0	0	19	131	0	0	150	248
S16	Ceiling @ center stirrup	47	75	33	108	117	51	0	0	0	164	281	318
S17	Ceiling @ NE corner stirrup	33	824	8,536	51	0	0	0	0	0	0	61	33
S18	Stirrup, N wall top @ ceiling	23	23	28	66	370	51	56	61	61	56	70	80
S19	Stirrup, N wall center	0	33	28	66	66	47	168	145	51	56	173	178
S20	Stirrup, N wall @ Zone 1 elevation	37	0	33	108	103	61	187	159	112	117	220	215
S21	N wall, Zone 1 shot elev., vert., outer	70	94	51	145	145	84	234	276	94	154	173	159
S22	Floor, upper, EW	0	0	0	0	0	0	0	0	0	0	0	0
S23	Stirrup, floor	819	632	0	0	1,835	0	304	285	0	103	379	314
S24	Floor, lower, EW	47	61	47	89	89	66	56	56	126	0	0	0
S25	Ceiling haunch @ center N wall	117	108	84	117	108	98	154	122	145	117	154	0
S26	Wall haunch @ center NE corner	0	0	0	0	0	0	351	342	328	154	183	197
S27	Stirrup, top of bullnose	47	51	89	98	108	159	154	150	178	215	225	239
S28	E wall @ door, vertical, outer	0	0	0	0	0	0	0	0	0	0	0	0
S29	Shrapnel plate anchor, NS	164	866	468	1114	1273	599	1530	1404	0	0	0	0
S30	Noise gauge (ceiling @ center N wall)	23	0	0	0	0	0	80	94	108	257	0	0
S31	Anvil bolt, vertical	0	1161	0	0	0	0	1563	2761	2059	0	0	0

Table A5. Maximum tensile safety factors (SF) to yield.

Test No.:		1	2	3	4	5	6	7	8	9	14	15	16
Test series (QSCT):		2	3	1	5	6	4	8	9	7	10	11	11
C4 explosive weight (lb):		0.52	0.52	0.3	1.03	1.03	0.6	2.07	2.07	1.21	1.51	2.58	2.58
% of full-scale charge (zone):		25 (1)	25 (1)	25 (4)	50 (1)	50 (1)	50 (4)	100 (1)	100 (1)	100 (4)	125 (4)	125 (1)	125 (1)
Test date (1994):		3/18	4/5	4/5	4/12	4/12	4/12	4/27	4/27	4/27	6/7	6/7	6/8
Gauge													
C1	Bullnose, EW, outer	25.00	25.00	7.81	7.35	11.36	6.25	15.63	25.00	5.21	3.79	25.00	20.83
C2	Bullnose, EW, inner	20.83	20.83	11.36	6.25	5.21	7.35	8.33	8.93	4.46	4.17	7.81	7.81
C3	Bullnose, NS, inner	16.67	15.63	8.33	2.78	2.91	4.17	5.68	6.25	3.13	4.03	5.95	7.35
C4	Floor bottom, NS	—	4.63	10.42	**0.91**	**0.97**	5.68	2.40	2.66	6.58	2.98	2.08	2.50
C5	Floor top, NS	1.39	1.87	11.36	**0.64**	1.07	6.94	5.21	4.03	11.36	3.91	5.43	4.63
C6	Door frame, S corner, outer	—	2.55	3.91	1.92	1.92	1.98	1.30	1.21	**0.71**	1.14	**0.72**	1.02
C7	N wall, center, vertical, outer	2.12	1.87	3.47	1.56	1.52	2.08	**0.68**	**0.73**	1.03	**0.86**	1.04	**0.66**
C8	N wall, center, vertical, inner	5.00	4.31	5.95	3.79	3.79	3.21	2.27	2.05	**0.96**	1.67	5.95	1.42
C9	N wall, top, vertical, outer	6.25	8.33	13.89	7.81	6.58	7.35	9.62	13.89	3.21	5.00	7.81	8.93
C10	Ceiling @ N wall, NS, outer	15.63	9.62	20.83	10.42	8.93	17.86	10.42	13.89	3.05	6.58	7.81	6.94
C11	Ceiling @ center, NS, upper	2.16	1.84	3.29	1.28	1.24	2.55	**0.84**	**0.87**	1.64	1.76	1.32	1.24
C12	Ceiling @ center, NS, lower	4.17	3.91	2.50	3.47	3.47	1.36	2.91	2.91	1.49	3.21	**0.95**	**0.88**
C13	Floor, NS, upper	2.78	6.25	25.00	1.03	1.47	12.50	9.62	25.00	17.86	10.42	7.81	9.62
C14	N wall, center, EW, inner	2.16	1.89	3.47	1.60	1.58	2.27	**0.93**	**0.80**	1.21	2.66	1.81	1.69
C15	N wall, center, EW, outer	8.33	6.58	8.93	5.68	5.43	4.46	3.21	1.49	1.45	2.55	2.40	2.16
S1	Bullnose door, NS	75.00	93.75	13.39	53.57	39.47	7.28	29.41	26.32	5.32	4.64	17.05	27.78
S2	Bullnose, EW, outer mat	258.62	184.73	63.08	117.55	107.76	44.59	64.66	83.43	29.06	30.07	66.31	103.45
S3	Bullnose, NS, outer mat	—	—	—	—	—	—	—	—	—	—	—	—
S4	North wall @ W corner, outer mat	117.55	99.47	152.13	68.06	76.06	69.90	45.37	41.05	49.73	53.88	35.92	31.54
S5	North wall @ W corner, inner mat	—	—	—	—	—	—	—	—	—	—	—	—
S6	Door, NS	11.11	11.54	9.80	—	—	—	4.16	4.69	7.11	4.39	3.48	3.49
S7	Door trim, S corner, outer	68.06	68.06	99.47	41.05	42.40	41.05	20.36	17.24	15.12	11.44	58.78	11.97
S8	Floor, NS, lower	73.89	—	—	—	—	—	—	—	—	—	—	—
S9	N wall, Zone 1 shot elev., vert., inner	—	—	—	—	—	—	—	—	—	—	—	—
S10	N wall, center, vertical, outer	39.79	—	—	—	—	—	8.29	7.84	9.44	7.20	5.85	4.74
S11	N wall, center, vertical, inner	129.31	99.47	143.68	89.18	80.82	69.90	48.80	41.71	43.83	—	66.31	66.31
S12	N wall, top, vertical, inner	57.47	—	—	—	—	—	—	—	—	—	—	—
S13	Ceiling @ N wall, NS, inner	28.74	25.61	34.95	17.71	17.47	22.10	7.70	7.05	11.49	9.72	8.95	7.14
S14	Ceiling @ center, NS, lower	86.21	—	—	—	—	—	235.11	215.52	56.22	71.84	63.08	48.80
S15	Ceiling @ center, NS, upper	36.95	34.48	34.48	—	—	—	11.86	9.11	—	—	7.37	7.54
S16	Ceiling @ center stirrup	1293.10	862.07	862.07	646.55	646.55	646.55	—	—	—	287.36	369.46	431.03
S17	Ceiling @ NE corner stirrup	172.41	2.41	2.75	73.89	129.31	129.31	—	—	—	—	71.84	58.78
S18	Stirrup, N wall top @ ceiling	862.07	323.28	517.24	258.62	129.31	258.62	161.64	117.55	323.28	369.46	143.68	112.44
S19	Stirrup, N wall center	—	862.07	646.55	431.03	431.03	646.55	369.46	215.52	287.36	198.94	143.68	136.12
S20	Stirrup, N wall @ Zone 1 elevation	369.46	—	646.55	287.36	323.28	431.03	184.73	198.94	235.11	198.94	258.62	235.11
S21	N wall, Zone 1 shot elev., vert., outer	86.21	80.82	123.15	56.22	53.88	83.43	25.86	25.61	36.43	26.12	21.92	17.47
S22	Floor, upper, EW	—	—	—	—	—	—	—	—	—	—	—	—
S23	Stirrup, floor	64.66	78.37	—	—	25.61	—	112.44	117.55	—	369.46	862.07	862.07
S24	Floor, lower, EW	86.21	129.31	136.12	78.37	69.90	103.45	58.78	61.58	61.58	—	—	—
S25	Ceiling haunch @ center N wall	64.66	64.66	78.37	36.43	39.79	51.72	25.86	26.12	34.03	29.06	24.40	—
S26	Wall haunch @ center NE corner	—	—	—	—	—	—	19.74	15.96	20.69	22.10	15.30	17.71
S27	Stirrup, top of bullnose	369.46	287.36	287.36	143.68	184.73	172.41	258.62	258.62	112.44	92.36	123.15	117.55
S28	E wall @ door, vertical, outer	—	—	—	—	—	—	—	—	—	—	—	—
S29	Shrapnel plate anchor, NS	6.67	5.21	10.79	3.11	3.09	4.95	2.44	3.00	—	—	—	—
S30	Noise gage (ceiling @ center N wall)	517.24	—	—	—	—	—	152.13	71.84	123.15	47.02	—	—
S31	Anvil bolt, vertical	—	1.27	—	—	—	—	**0.21**	**0.21**	**0.21**	—	—	—

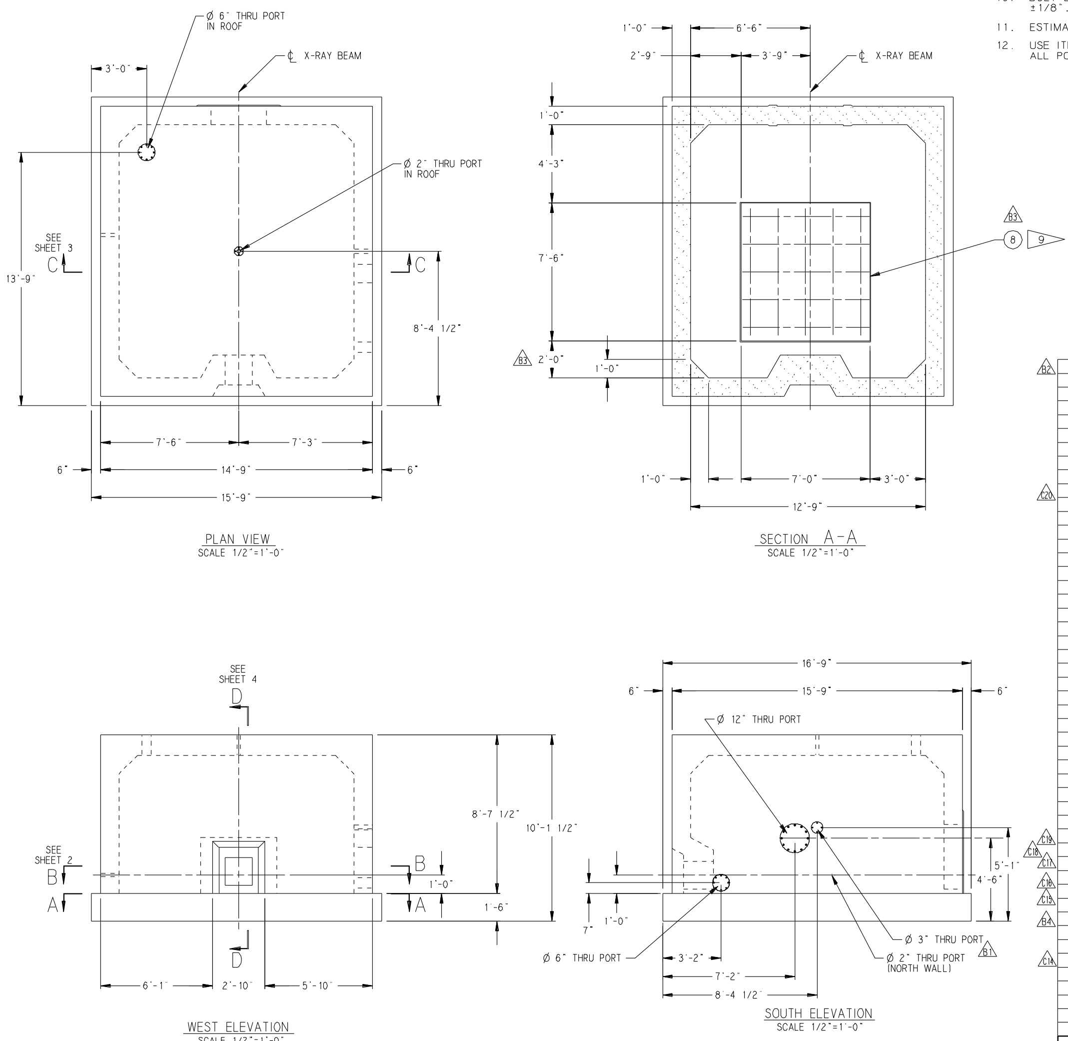
Bold type indicates yielding (SF < 1).

Table A6. Maximum compressive safety factors (SF) to yield.

Test No.:		1	2	3	4	5	6	7	8	9	14	15	16
Test series (QSCT):		2	3	1	5	6	4	8	9	7	10	11	11
C4 explosive weight (lb):		0.52	0.52	0.3	1.03	1.03	0.6	2.07	2.07	1.21	1.51	2.58	2.58
% of full-scale charge (zone):		25 (1)	25 (1)	25 (4)	50 (1)	50 (1)	50 (4)	100 (1)	100 (1)	100 (4)	125 (4)	125 (1)	125 (1)
Test date (1994):		3/18	4/5	4/5	4/12	4/12	4/12	4/27	4/27	4/27	6/7	6/7	6/8
Gauge													
C1	Bullnose, EW, outer	470.1	156.7	39.2	32.1	32.8	22.7	52.2	64.1	15.2	18.8	78.3	78.3
C2	Bullnose, EW, inner	235.0	176.3	74.2	28.8	34.4	32.8	61.3	61.3	28.2	25.6	34.4	34.4
C3	Bullnose, NS, inner	235.0	201.5	108.5	44.1	42.7	78.3	67.2	58.8	44.1	70.5	78.3	70.5
C4	Floor bottom, NS	—	141.0	128.2	40.3	35.3	94.0	100.7	88.1	156.7	117.5	352.6	176.3
C5	Floor top, NS	56.4	36.2	108.5	12.9	23.5	64.1	39.2	40.3	94.0	56.4	88.1	35.3
C6	Door frame, S corner, outer	—	52.2	70.5	67.2	56.4	41.5	35.3	27.7	28.2	56.4	20.1	16.6
C7	N wall, center, vertical, outer	38.1	41.5	47.0	35.3	37.1	40.3	52.2	40.3	19.6	30.0	282.1	23.1
C8	N wall, center, vertical, inner	47.0	40.3	67.2	38.1	34.4	39.2	18.3	20.4	11.9	28.8	10.6	19.1
C9	N wall, top, vertical, outer	44.1	40.3	58.8	24.7	24.3	30.0	15.7	15.2	9.9	18.3	13.7	12.8
C10	Ceiling @ N wall, NS, outer	100.7	74.2	128.2	56.4	58.8	78.3	45.5	40.3	25.6	50.4	32.1	24.7
C11	Ceiling @ center, NS, upper	78.3	67.2	94.0	70.5	67.2	117.5	282.1	282.1	58.8	88.1	176.3	235.0
C12	Ceiling @ center, NS, lower	18.8	13.1	20.1	9.3	8.2	11.9	5.6	5.1	6.2	4.5	3.0	2.6
C13	Floor, NS, upper	70.5	67.2	235.0	22.4	20.4	156.7	67.2	108.5	176.3	74.2	47.0	52.2
C14	N wall, center, EW, inner	37.1	40.3	45.5	36.2	40.3	40.3	41.5	29.4	21.4	48.6	45.5	48.6
C15	N wall, center, EW, outer	94.0	67.2	108.5	61.3	54.2	58.8	32.8	19.1	19.3	41.5	48.6	31.3
S1	Bullnose door, NS	100.0	115.4	18.1	71.4	68.2	9.6	29.4	48.4	3.3	3.8	13.4	20.3
S2	Bullnose, EW, outer mat	431.0	161.6	44.6	112.4	117.6	25.9	58.8	73.9	18.7	18.9	103.4	89.2
S3	Bullnose, NS, outer mat	—	—	—	—	—	—	—	—	—	—	—	—
S4	North wall @ W corner, outer mat	184.7	184.7	235.1	136.1	143.7	112.4	112.4	68.1	73.9	83.4	63.1	61.6
S5	North wall @ W corner, inner mat	—	—	—	—	—	—	—	—	—	—	—	—
S6	Door, NS	11.1	16.7	10.3	—	—	—	12.4	12.5	12.7	9.4	9.1	8.2
S7	Door trim, S corner, outer	143.7	215.5	129.3	152.1	152.1	117.6	76.1	60.1	107.8	99.5	46.2	43.8
S8	Floor, NS, lower	215.5	—	—	—	—	—	—	—	—	—	—	—
S9	N wall, Zone 1 shot elev. vert., inner	—	—	—	—	—	—	—	—	—	—	—	—
S10	N wall, center, vertical, outer	68.1	—	—	—	—	—	32.7	41.7	29.4	27.5	15.3	32.3
S11	N wall, center, vertical, inner	86.2	64.7	107.8	66.3	61.6	69.9	30.1	31.9	38.6	—	103.4	103.4
S12	N wall, top, vertical, inner	103.4	—	—	—	—	—	—	—	—	—	—	—
S13	Ceiling @ N wall, NS, inner	51.7	47.0	66.3	45.4	43.8	57.5	35.9	258.6	31.5	63.1	15.8	369.5
S14	Ceiling @ center, NS, lower	63.1	—	—	—	—	—	18.3	16.5	24.4	19.0	12.0	11.0
S15	Ceiling @ center, NS, upper	129.3	117.6	117.6	—	—	—	646.6	92.4	—	—	80.8	48.8
S16	Ceiling @ center stirrup	258.6	161.6	369.5	112.4	103.4	235.1	—	—	—	73.9	43.1	38.0
S17	Ceiling @ NE corner stirrup	369.5	14.7	1.4	235.1	—	—	—	—	—	—	198.9	369.5
S18	Stirrup, N wall top @ ceiling	517.2	517.2	431.0	184.7	32.7	235.1	215.5	198.9	198.9	215.5	172.4	152.1
S19	Stirrup, N wall center	—	369.5	431.0	184.7	184.7	258.6	71.8	83.4	235.1	215.5	69.9	68.1
S20	Stirrup, N wall @ Zone 1 elevation	323.3	—	369.5	112.4	117.6	198.9	64.7	76.1	107.8	103.4	55.0	56.2
S21	N wall, Zone 1 shot elev., vert., outer	172.4	129.3	235.1	83.4	83.4	143.7	51.7	43.8	129.3	78.4	69.9	76.1
S22	Floor, upper, EW	—	—	—	—	—	—	—	—	—	—	—	—
S23	Stirrup, floor	14.8	19.2	—	—	6.6	—	39.8	42.4	—	117.6	31.9	38.6
S24	Floor, lower, EW	258.6	198.9	258.6	136.1	136.1	184.7	215.5	215.5	95.8	—	—	—
S25	Ceiling haunch @ center N wall	103.4	112.4	143.7	103.4	112.4	123.2	78.4	99.5	83.4	103.4	78.4	—
S26	Wall haunch @ center NE corner	—	—	—	—	—	—	34.5	35.4	36.9	78.4	66.3	61.6
S27	Stirrup, top of bullnose	258.6	235.1	136.1	123.2	112.4	76.1	78.4	80.8	68.1	56.2	53.9	50.7
S28	E wall @ door, vertical, outer	—	—	—	—	—	—	—	—	—	—	—	—
S29	Shrapnel plate anchor, NS	42.9	8.1	15.0	6.3	5.5	11.7	4.6	5.0	—	—	—	—
S30	Noise gauge (ceiling @ center N wall)	517.2	—	—	—	—	—	152.1	129.3	112.4	47.0	—	—
S31	Anvil bolt, vertical	—	6.0	—	—	—	—	4.5	2.5	3.4	—	—	—

Appendix B Structural Drawings

AAA92-106177
(sheets 1-5)



NOTES
UNLESS OTHERWISE SPECIFIED:

1. ALL DIMENSIONS ARE IN FEET AND INCHES.
2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
3. SURFACE TEXTURE PER ANSI B46.1-1978.
4. BREAK EDGES AND DEBURR .12 MAX. RADIUS OR CHAMFER.
5. CONCRETE SPECIFICATIONS: ACI 301. STRENGTH f'_c = 6,000 PSI AT 28 DAYS
   3/8" MAXIMUM AGGREGATE SIZE MIX (CALTRANS STANDARD SPECIFICATIONS, LATEST DATE, SECTION 90-PORTLAND CEMENT CONCRETE)
   FOUR CYLINDERS REQUIRED
   ONE AT 10 DAYS
   TWO AT 28 DAYS
   ONE SPARE
6. CONCRETE FINISHING: ACI 301, FLOAT FINISH.
7. TORQUE: 1" NUTS TO 200 FT-LBS.
8. SEE DRAWING AAA93-103451 FOR INSTRUMENTATION ARRANGEMENT.
9. MATCH DRILL PLATE HOLES WITH BOLTS AFTER CONCRETE IS POURED AND SET. PLATE MAY HAVE ADDITIONAL HOLES FOR GROUT FILLING AS REQUIRED EXCEPT IN NOTED AREA. THESE HOLES MUST BE PLUGED FLUSH AFTER GROUT IS POURED. USE BURKE EPOXY METALIC (NON-SHRINK, EXPANSIVE) GROUT NOM. 1" THICK.
10. BOLT LOCATIONS DIMENSIONS TOLERANCES ±1/8". ALL OTHER TOLERANCES ±1/4".
11. ESTIMATED TOTAL WEIGHT = 96 TONS.
12. USE ITEM 48 AS GASKET MATERIAL FOR ALL PORTS AND ACCESS OPENINGS.

	NO REQD	PART / LLNL STK NO	DESCRIPTION / MATERIAL		SPEC NO	ITEM
B2	1	93-101498	SHRAPNEL SHIELD ASSEMBLY			49
	AR		SHEET, NEOPRENE, 1/16" THICK			48
	24		NUT, HEX, PLAIN, 7/8"-9UNC-2B	STEEL, ASTM A307		47
	32		NUT, HEX, PLAIN, 3/4"-10UNC-2B	STEEL, ASTM A307		46
	24		NUT, HEX, PLAIN, 5/8"-11UNC-2B	STEEL, ASTM A307		45
	2		FLANGE, BLIND, SLIP ON WELDING,FLAT FACE, 150 PSI, 12"IPS	STEEL		44
	4		FLANGE, BLIND, SOCKET WELD, FLAT FACE, 150 PSI, 6"IPS	STEEL		43
	2		FLANGE, BLIND, SOCKET WELD, FLAT FACE, 150 PSI, 3"IPS	STEEL		42
	4		FLANGE, BLIND, SOCKET WELD, FLAT FACE, 150 PSI, 2"IPS	STEEL		41
C20	AR		PLATE, 1/2" THICK	STEEL, ASTM A36		40
	AR		ANGLE, 8" X 8" X 1/2" THK.	STEEL, ASTM A36		39
	AR		NO. 8 REBAR	STEEL, ASTM A615 GRADE 60		38
	AR		NO. 6 REBAR	STEEL, ASTM A615 GRADE 60		37
	1		BAR, ROUND, COLD FINISH Ø1/2" X 49" LONG	STEEL, ASTM A10		36
	24		BOLT, HEAVY HEX, 7/8"-9 UNC-2A X 4" LONG	STEEL		35
	32		BOLT, HEAVY HEX, 3/4"-10 UNC-2A X 4" LONG	STEEL		34
	24		BOLT, HEAVY HEX, 5/8"-11 UNC-2A X 3" LONG	STEEL		33
	2		FLANGE, SLIP ON WELDING,FLAT FACE, 150 PSI, 12"IPS	STEEL		32
	4		FLANGE, SOCKET WELD, FLAT FACE, 150 PSI, 6"IPS	STEEL		31
	2		FLANGE, SOCKET WELD, FLAT FACE, 150 PSI, 3"IPS	STEEL		30
	4		FLANGE, SOCKET WELD, FLAT FACE, 150 PSI, 2"IPS	STEEL		29
	1		PIPE, 12"IPS, STANDARD ASTM A53 X 11.25" LONG	STEEL		28
	1		PIPE, 6"IPS, SCH40 ASTM A53 X 11" LONG	STEEL		27
	1		PIPE, 6"IPS, SCH40 ASTM A53 X 11.25" LONG	STEEL		26
	1		PIPE, 3"IPS, SCH40 ASTM A53 X 11.25" LONG	STEEL		25
	1		PIPE, 2"IPS, SCH40 ASTM A53 X 12.875" LONG	STEEL		24
	1		PIPE, 2"IPS, SCH40 ASTM A53 X 11.375" LONG	STEEL		23
	6		PIPE, 1-1/4"IPS X 23" LONG	STEEL		22
	10		TUBE, 1-1/16"OD X .250" WALL X 6" LONG	1018 STL		21
	10		TUBE, 1" OD X .219" WALL X 5.875" LONG	1018 STL		20
	1	(DOOR FRAME TOP)	CHANNEL, MC12 X 45 X 44" LONG	STEEL, ASTM A36		19
	2	(DOOR FRAME SIDES)	CHANNEL, MC12 X 45 X 42" LONG	STEEL, ASTM A36		18
	1	(DOOR FRAME BOTTOM)	CHANNEL, C12 X 20.7 X 44" LONG	STEEL, ASTM A36		17
	9		PIPE, 1 1/4" IPS x 12" LONG STEEL, ASTM A53 GRADE B SCH 80			16
C19	31		PLATE, 2 1/4" SQUARE x 5/16" THK	STEEL, ASTM A36		15
C18	40		WASHER, FLAT, 2" O.D. x 1 1/8" I.D. x 3/16" THK	STL		14
C17	80		NUT, HEX, PLAIN, 1"-8 UNC-2B	STEEL, ASTM A307		13
C16	9		BOLT, HEX HEAD, 1"-8 UNC-2A x 16" LONG	STEEL, ASTM A307		12
C15	25		ROD, THREADED, 1"-8 UNC-2A x 12" LONG	STEEL, ASTM A307		11
	6		ROD, THREADED, 1"-8 UNC-2A X 23"LONG	STEEL, ASTM A307		10
B4	AR		PLATE, 2" THICK	STEEL, ASTM A36		9
	AR		PLATE, 1 1/2" THICK	STEEL, ASTM A36		8
	2		PLATE, 1" THICK	STEEL, ASTM A36		7
C14	AR		NO. 11 REBAR	STEEL, ASTM A615 GRADE 60		6
	-		PLATE, 1/8" THICK	STEEL		5
	AR		NO. 7 REBAR	STEEL, ASTM A615 GRADE 60		4
	AR		NO. 5 REBAR	STEEL, ASTM A615 GRADE 60		3
	AR		NO. 3 REBAR (STIRRUP)	STEEL, ASTM A615 GRADE 40		2
	AR		CONCRETE		SEE NOTE 5	1

CINTINUED ON SHEET 2

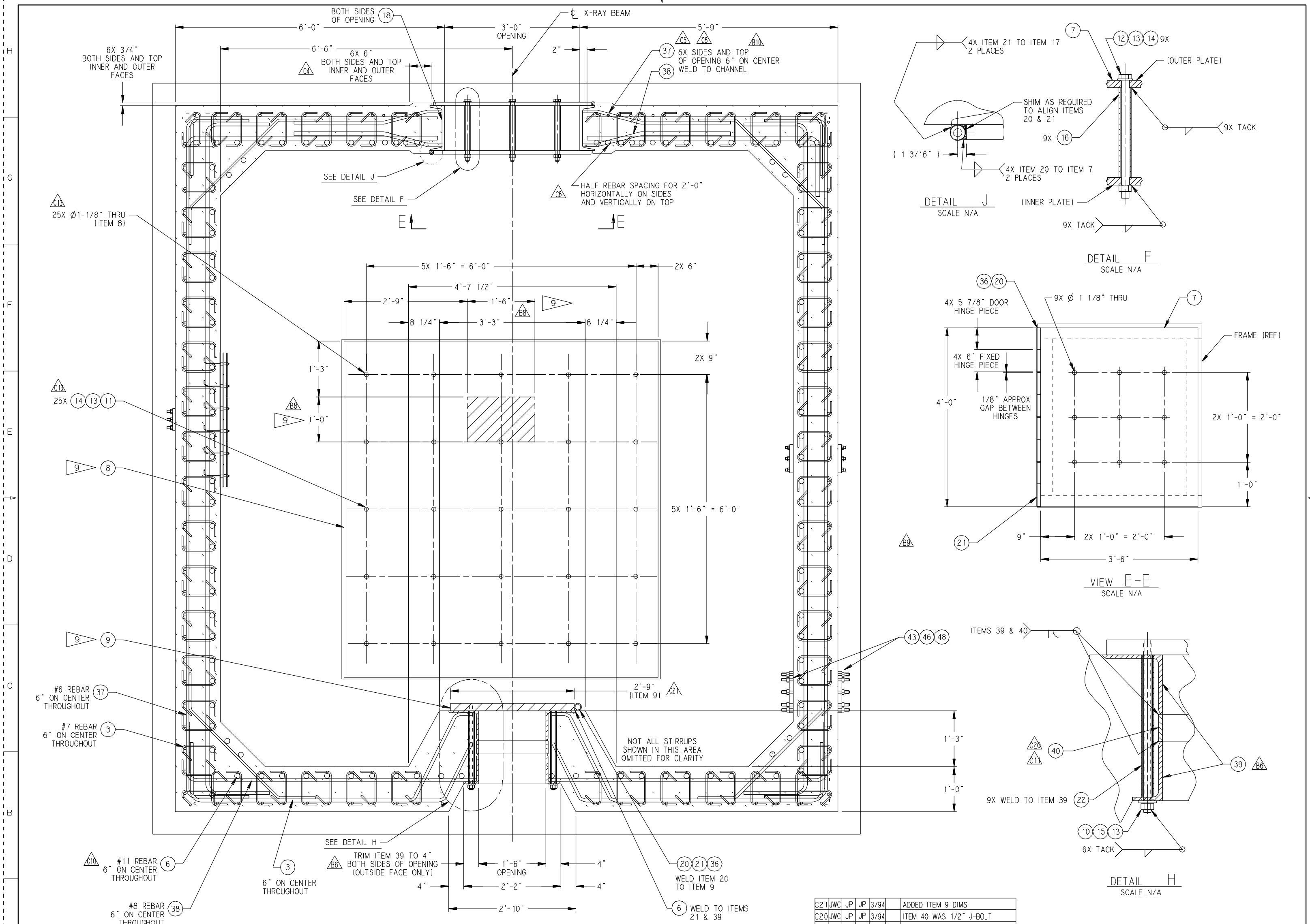
LTR	DWN	CHK	APVD	DATE	ZONE	CHANGE
C14	JWC	JP	JP	3/94		ITEM 6 WAS 1/2" STEEL PLATE
C13	JWC	JP	JP	3/94		ANVIL BOLT COUNT WAS 36
C12	JWC	JP	JP	3/94		REMOVED STEP JOINT WALL/FLOOR
C11	JWC	JP	JP	3/94		ADDED STEEL BETWEEN ANGLES AT B/N
C10	JWC	JP	JP	3/94		INNER MAT SIZE WAS #7
C9	JWC	JP	JP	3/94		ADDED TAILS TO CEILING REBAR
C8	JWC	JP	JP	3/93		RAISED BULLNOSE OPENING 2-1/2"
C7	JWC	JP	JP	3/94		REMOVED REBAR LOOP
C6	JWC	JP	JP	3/94		ADDED REBAR AT DOOR
C5	JWC	JP	JP	3/94		REMOVED J-BOLTS AT DOOR
C4	JWC	JP	JP	3/94		ADDED CONCRETE AT DOOR
C3	JWC	JP	JP	3/94		ADDED CONCRETE AT BULLNOSE
C2	JWC	JP	JP	3/94		MODIFIED STIRRUP SHAPE
C1	JWC	JP	JP	3/94		MODIFIED TO "AS-BUILT" CONDITION
B10	JWC	JP	JP	8/93		ADDED ITEM 40 TO BOTTOM
B9	JWC	JP	JP	8/93		ADDED 7X COUNTERBORES
B8	JWC	JP	JP	8/93		ADDED KEEPOUT ZONE (NOTE 9)
B7	JWC	JP	JP	8/93		ADDED NOTED REBAR LOOP
B6	JWC	JP	JP	8/93		ADDED ITEM 39 ON OUTSIDE
B5	JWC	JP	JP	8/93		REVISED NOTE 9
B4	JWC	JP	JP	8/93		MATERIAL ITEM 9 WAS GRADE 42
B3	JWC	JP	JP	8/93		RELOCATED ITEM 8
B2	JWC	JP	JP	8/93		ADDED ITEM 49
B1	JWC	JP	JP	8/93		RELOCATED NOTED 2" & 3" PORTS
A	JWC	JP	JP	5/93		CHANGED STIRRUP SPACING TO 6"
A	JWC	JP	JP	5/93		CHANGED REBAR SPACING TO 6"
A	JWC	JP	JP	5/93		ADDED ITEMS 37 THRU 48

DWN	S. KRAMER	8-92
CHK	J.W. CLEMENTS	4-93
APVD	J.W. PASTRNAK	4-93
CLASSIFIED BY:		
TITLE		DATE

LAWRENCE LIVERMORE NATIONAL LABORATORY
MECHANICAL ENGINEERING DEPT
UNIVERSITY OF CALIFORNIA

CLASSIFICATION

MAJOR UNIT (U) TITLES CLASSIFICATION
SITE-300 BUNKER-801
SUBASSY
1/4 SCALE CONTAINED FIRING
DETAIL
FIRING CHAMBER
SHOWN ON AAA
ACCT NO 5095-05
DRAWING NO AAA92-106177-0C
SCALE |←4'-0"→| SHEET 1 OF 5

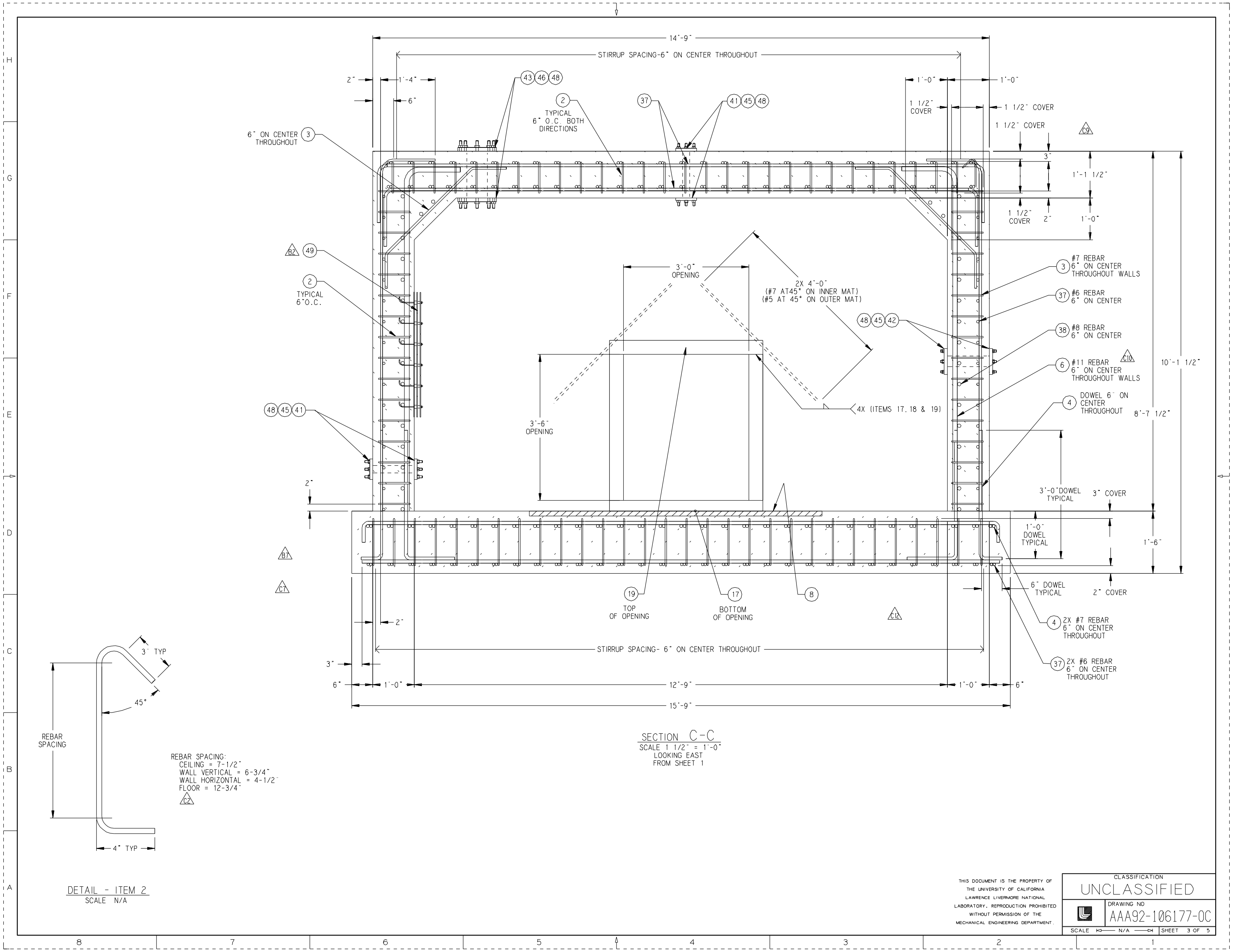


LTR	DWN	CHK	APVD	DATE	ZONE	CHANGE
C21	JWC	JP	JP	3/94		ADDED ITEM 9 DIMS
C20	JWC	JP	JP	3/94		ITEM 40 WAS 1/2" J-BOLT
C19	JWC	JP	JP	3/94		ITEM 15 COUNT WAS 42
C18	JWC	JP	JP	3/94		ITEM 14 COUNT WAS 45
C17	JWC	JP	JP	3/94		ITEM 13 COUNT WAS 51
C16	JWC	JP	JP	3/94		ITEM 11 COUNT WAS 36
C15	JWC	JP	JP	3/94		ITEM 11 WAS HEX BOLT

CLASSIFICATION
UNCLASSIFIED

DRAWING NO
AAA92-106177-0C

SCALE N/A
SHEET 2 OF 5


14'-9"
STIRRUP SPACING-6" ON CENTER THROUGHOUT
2"
1'-4"
6"
43 46 48
2
TYPICAL
6" O.C. BOTH
DIRECTIONS
37
41 45 48
1'-0"
1'-0"
1 1/2"
COVER
1 1/2" COVER
1 1/2" COVER
6" ON CENTER
THROUGHOUT
3
3"
1'-1 1/2"
1 1/2"
COVER
2"
1'-0"
49
2
TYPICAL
6"O.C.
3'-0"
OPENING
2X 4'-0"
(#7 AT45° ON INNER MAT)
(#5 AT 45° ON OUTER MAT)
3 #7 REBAR
6" ON CENTER
THROUGHOUT WALLS
37 #6 REBAR
6" ON CENTER
48 45 42
38 #8 REBAR
6" ON CENTER
6 #11 REBAR
6" ON CENTER
THROUGHOUT WALLS
10'-1 1/2"
48 45 41
4X (ITEMS 17, 18 & 19)
4 DOWEL 6" ON
CENTER
THROUGHOUT
8'-7 1/2"
3'-6"
OPENING
2"
3'-0"DOWEL
TYPICAL
3" COVER
1'-0"
DOWEL
TYPICAL
1'-6"
6" DOWEL
TYPICAL
2" COVER
19
TOP
OF OPENING
17
BOTTOM
OF OPENING
8
2"
4 2X #7 REBAR
6" ON CENTER
THROUGHOUT
STIRRUP SPACING- 6" ON CENTER THROUGHOUT
3"
37 2X #6 REBAR
6" ON CENTER
THROUGHOUT
6"
1'-0"
12'-9"
1'-0"
6"
15'-9"
SECTION C-C
SCALE 1 1/2" = 1'-0"
LOOKING EAST
FROM SHEET 1
3" TYP
45°
REBAR
SPACING
REBAR SPACING:
CEILING = 7-1/2"
WALL VERTICAL = 6-3/4"
WALL HORIZONTAL = 4-1/2"
FLOOR = 12-3/4"
4" TYP
DETAIL - ITEM 2
SCALE N/A
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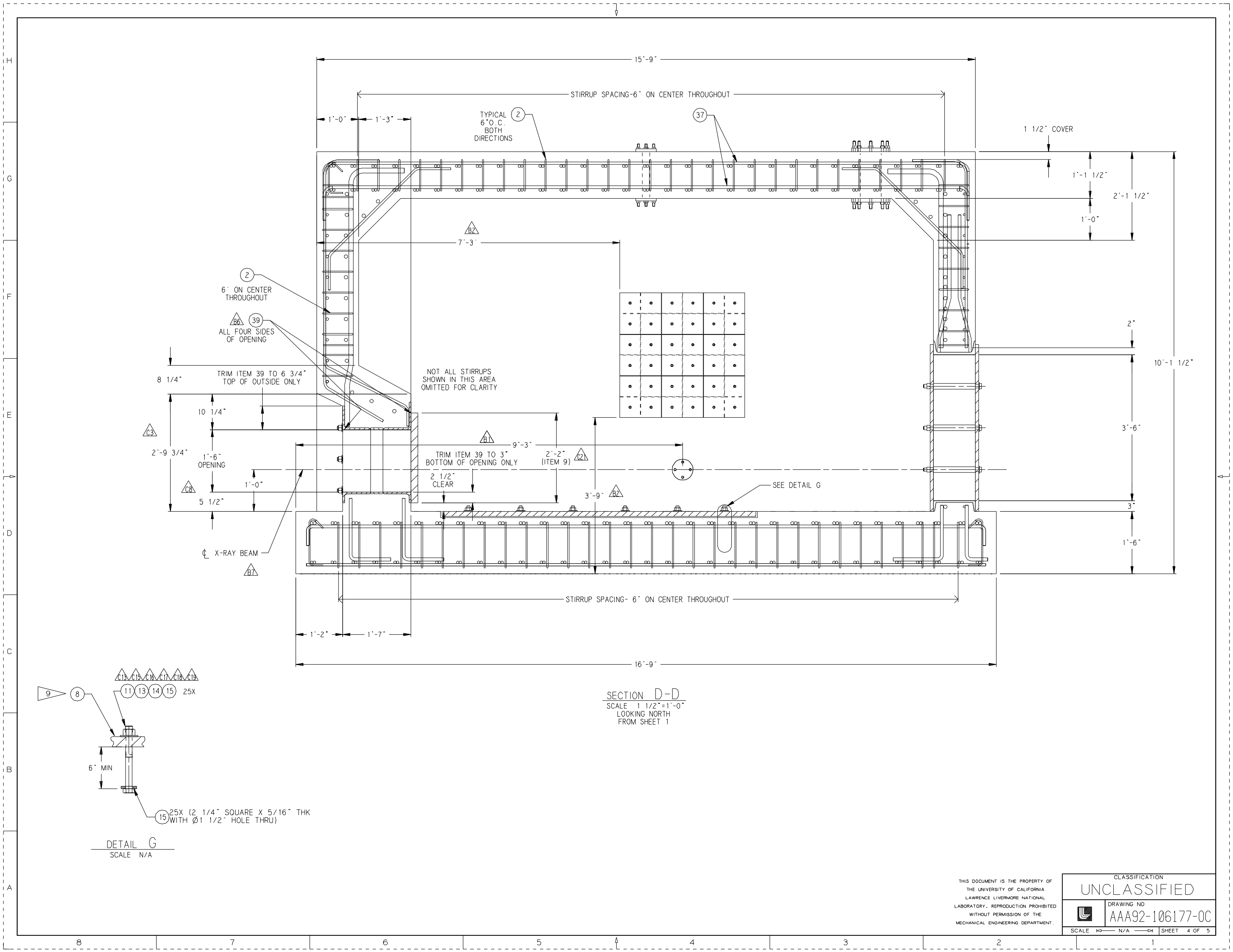
CLASSIFICATION
UNCLASSIFIED
DRAWING NO
AAA92-106177-0C
SCALE N/A
SHEET 3 OF 5



15'-9"
STIRRUP SPACING-6" ON CENTER THROUGHOUT
1'-0"
1'-3"
TYPICAL 2 6" O.C. BOTH DIRECTIONS
37
1 1/2" COVER
1'-1 1/2"
2'-1 1/2"
1'-0"
7'-3"
B2
2 6" ON CENTER THROUGHOUT
B6 39 ALL FOUR SIDES OF OPENING
2"
10'-1 1/2"
8 1/4"
TRIM ITEM 39 TO 6 3/4" TOP OF OUTSIDE ONLY
NOT ALL STIRRUPS SHOWN IN THIS AREA OMITTED FOR CLARITY
10 1/4"
C3
B1
9'-3"
3'-6"
2'-9 3/4"
1'-6" OPENING
TRIM ITEM 39 TO 3" BOTTOM OF OPENING ONLY
2'-2" (ITEM 9)
B2
2 1/2" CLEAR
C8
1'-0"
3'-9"
B2
SEE DETAIL G
5 1/2"
3"
1'-6"
℄ X-RAY BEAM
B7
STIRRUP SPACING- 6" ON CENTER THROUGHOUT
1'-2"
1'-7"
16'-9"
SECTION D-D
SCALE 1 1/2"=1'-0"
LOOKING NORTH
FROM SHEET 1
9 8
11 13 14 15 25X
6" MIN
15 25X (2 1/4" SQUARE X 5/16" THK WITH Ø1 1/2" HOLE THRU)
DETAIL G
SCALE N/A
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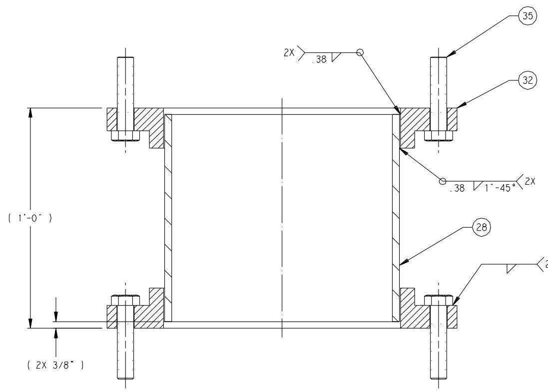
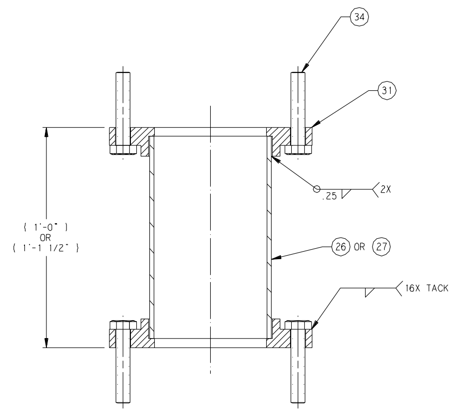
CLASSIFICATION
UNCLASSIFIED
DRAWING NO
AAA92-106177-0C
SCALE N/A
SHEET 4 OF 5



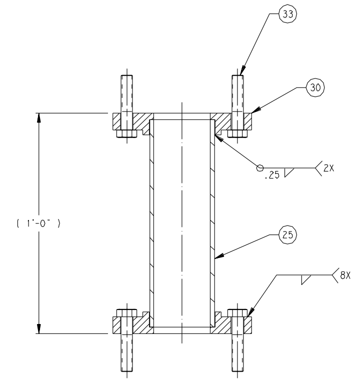
DETAIL FOR 12" FLANGE ASSEMBLY

(NOT ALL BOLTS SHOWN FOR CLARITY)



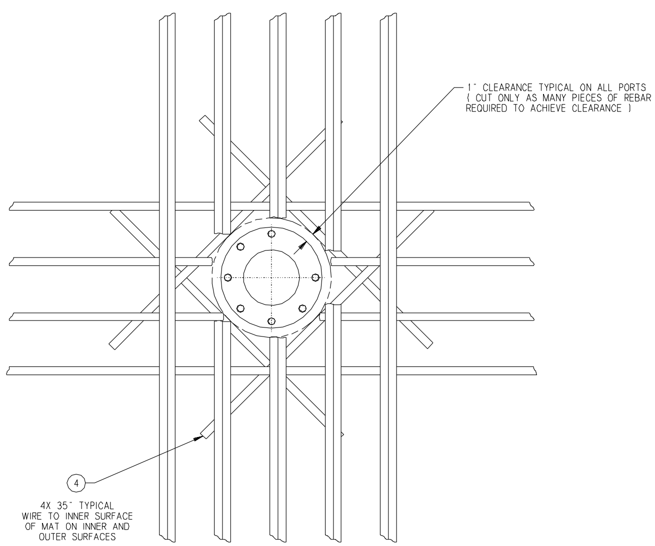
DETAIL FOR 6" FLANGE ASSEMBLY

(NOT ALL BOLTS SHOWN FOR CLARITY)



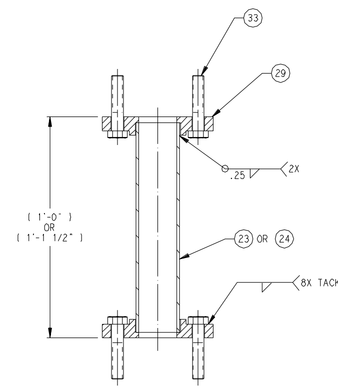
DETAIL FOR 3" FLANGE ASSEMBLY

(NOT ALL BOLTS SHOWN FOR CLARITY)



TYPICAL PORT OPENING FOR FLANGE ASSEMBLIES

(6" FLANGE ASSEMBLY SHOWN)



DETAIL FOR 2" FLANGE ASSEMBLY

(NOT ALL BOLTS SHOWN FOR CLARITY)

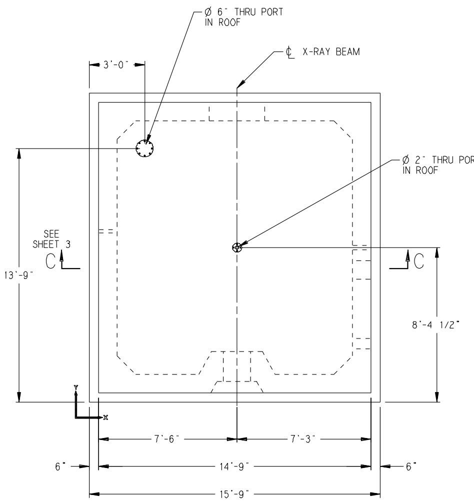
CLASSIFICATION
UNCLASSIFIED

DRAWING NO
AAA92-106177-0C

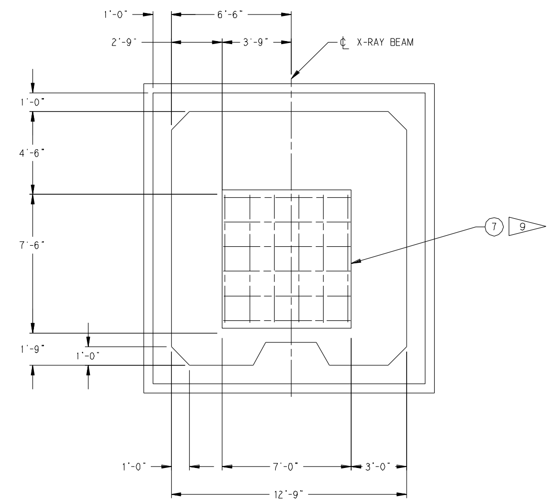
SCALE N/A | SHEET 5 OF 5

Appendix C Instrumentation Drawings

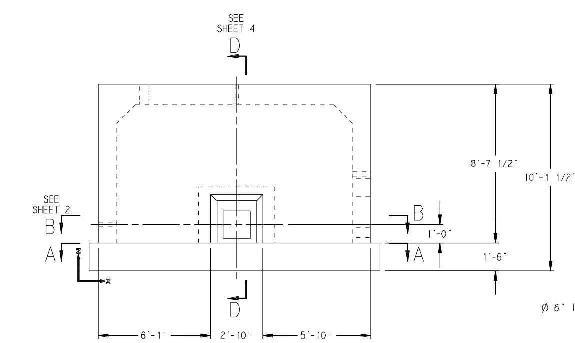
AAA93-103451



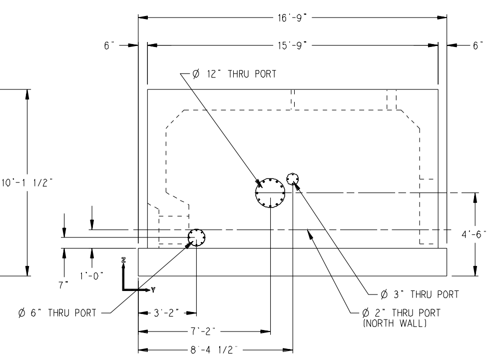
PLAN VIEW
SCALE 1/2"=1'-0"



SECTION A-A
SCALE 1/2"=1'-0"



WEST ELEVATION
SCALE 1/2"=1'-0"



SOUTH ELEVATION
SCALE 1/2"=1'-0"

NOTES
UNLESS OTHERWISE SPECIFIED:

1. ALL DIMENSIONS ARE IN FEET AND INCHES.
2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
3. SURFACE TEXTURE PER ANSI B46.1-1978.
4. WELD STRAIN GAGES S1 THRU S31 ONTO REBAR OR STIRRUP NEAREST LOCATION SHOWN IN CHART.
5. GAUGES ARE SHOWN SCHEMATICLY ONLY. NOT TO SCALE IN REPRESENTATION. SOME GAUGES MAY BE SHOWN OUT OF ACTUAL LOCATION FOR CLARITY. GAUGES NOT SHOWN IN ALL VIEWS ARE OMITTED FOR CLARITY.
6. CONCRETE GAUGES ARE IN THE SAME PLANE AS THE INNER FACE OF THE ADJACENT REBAR MAT.
7. WELD STRAIN GAGE S29 ONTO J-BOLT NEAREST LOCATION SHOWN IN CHART.

STRAIN GAGE LOCATIONS ±1/2"

GAGE NO.	X	Y	Z	SENSING DIRECTION	GAGE TYPE
P1	8'-0"	2'-11"	2'-6"	Y-AXIS NEGATIVE	PRESSURE
P2	8'-0"	8'-4 1/2"	8'-10 1/2"	Z-AXIS POSITIVE	PRESSURE
P3	1'-7 1/2"	9'-3"	2'-6"	X-AXIS NEGATIVE	PRESSURE
P4	8'-0"	15'-1"	4'-0"	Y-AXIS POSITIVE	PRESSURE
C1	6'-10"	1'-6"	2'-6"	Y-AXIS	CONCRETE
C2	6'-1"	2'-2"	2'-8"	60° from X-AXIS	CONCRETE
C3	5'-0"	1'-3"	2'-8"	X-AXIS	CONCRETE
C4	8'-3"	9'-7"	3"	X-AXIS	CONCRETE
C5	8'-3"	9'-7"	1'-3"	X-AXIS	CONCRETE
C6	6'-0"	15'-11"	5'-1"	45° from X-AXIS	CONCRETE
C7	9"	8'-6"	5'-0"	Z-AXIS	CONCRETE
C8	1'-2"	8'-6"	5'-0"	Z-AXIS	CONCRETE
C9	9"	8'-6"	6'-3"	Z-AXIS	CONCRETE
C10	2'-6"	8'-11"	9'-11"	X-AXIS	CONCRETE
C11	8'-0"	8'-11"	9'-11"	X-AXIS	CONCRETE
C12	8'-0"	8'-11"	9'-3"	X-AXIS	CONCRETE
C13	8'-0"	9'-7"	1'-3"	X-AXIS	CONCRETE
C14	9"	8'-9"	5'-0"	Y-AXIS	CONCRETE
C15	1'-2"	8'-9"	5'-0"	Y-AXIS	CONCRETE
S1	8'-0"	2'-9"	2'-6"	X-AXIS	STEEL
S2	6'-8"	1'-1"	2'-6"	60° from X-AXIS	STEEL
S3	6'-0"	9"	2'-6"	X-AXIS	STEEL
S4	1'-3"	3'-0"	5'-3"	Y-AXIS	STEEL
S5	9"	3'-0"	5'-3"	Y-AXIS	STEEL
S6	8'-2"	14'-3"	3'-6"	X-AXIS	STEEL
S7	6'-2"	15'-10"	3'-11"	45° from X-AXIS	STEEL
S8	8'-10"	9'-3"	3"	X-AXIS	STEEL
S9	1'-4"	8'-6"	3'-0"	Z-AXIS	STEEL
S10	8"	8'-3"	5'-0'	Z-AXIS	STEEL
S11	1'-4"	8'-3"	5'-0"	Z-AXIS	STEEL
S12	1'-4"	8'-3"	7'-9"	Z-AXIS	STEEL
S13	2'-6"	8'-8"	9'-3"	X-AXIS	STEEL
S14	8'-0"	9'-2"	9'-3"	X-AXIS	STEEL
S15	8'-0"	9'-2"	9'-3"	X-AXIS	STEEL
S16	7'-9"	8'-10"	9'-6"	Z-AXIS	STEEL
S17	2'-6"	8'-6"	9'-6"	Z-AXIS	STEEL
S18	1'-0"	8'-3"	6'-3"	Z-AXIS	STEEL
S19	1'-0"	8'-3"	3'-8"	X-AXIS	STEEL
S20	1'-0"	8'-3"	1'-9"	X-AXIS	STEEL
S21	8"	8'-3"	3'-0"	Z-AXIS	STEEL
S22	8'-0"	9'-9"	1'-4"	Y-AXIS	STEEL
S23	8'-0"	9'-3"	1'-4"	Z-AXIS	STEEL
S24	7'-10"	7'-7"	2"	Y-AXIS	STEEL
S25	2'-0"	8'-4"	8'-6"	45°from X-AXIS	STEEL
S26	1'-9"	14'-11"	4'-11"	45° from X-AXIS	STEEL
S27	8'-0"	1'-0"	4'-9"	Y-AXIS	STEEL
S28	5'-9"	15'-11"	4'-0"	Z-AXIS	STEEL
S29	9"	7'-6"	5'-6"	X-AXIS	STEEL
S30	2'-0"	9'-2"	9'-11"	X-AXIS	STEEL
S31	6'-3"	7'-3"	1'-3"	X-AXIS	STEEL

		NO REQD	PART / LLNL STK NO	DESCRIPTION / MATERIAL	SPEC NO	ITEM
		2		THERMOCOUPLE, TYPE 'K', (MARKED T1 & T2)		6
		3		CONCRETE STRAIN GAGE (SPECIAL MARKED C13 - C15)		5
		31	CEA-06-062VW-350	STEEL STRAIN GAGE (WELDED)		4
		12	EATON MODEL CG4-159-6S	CONCRETE STRAIN GAGE (EMBEDDED)		3
		4	PCB MODEL 109A	PRESSURE TRANSDUCER		2
		1	92-106177	FIRING CHAMBER		1

LTR	DWN	CHK	APVD	DATE	ZONE	CHANGE
B3	JWC	JP	JP	3/94		NO REQD- 31 WAS 29 (ITEM 4)
B2	JWC	JP	JP	3/94		CHANGED GAUGE LOCATIONS
B1	JWC	JP	JP	3/94		ADDED ITEMS 5 AND 6

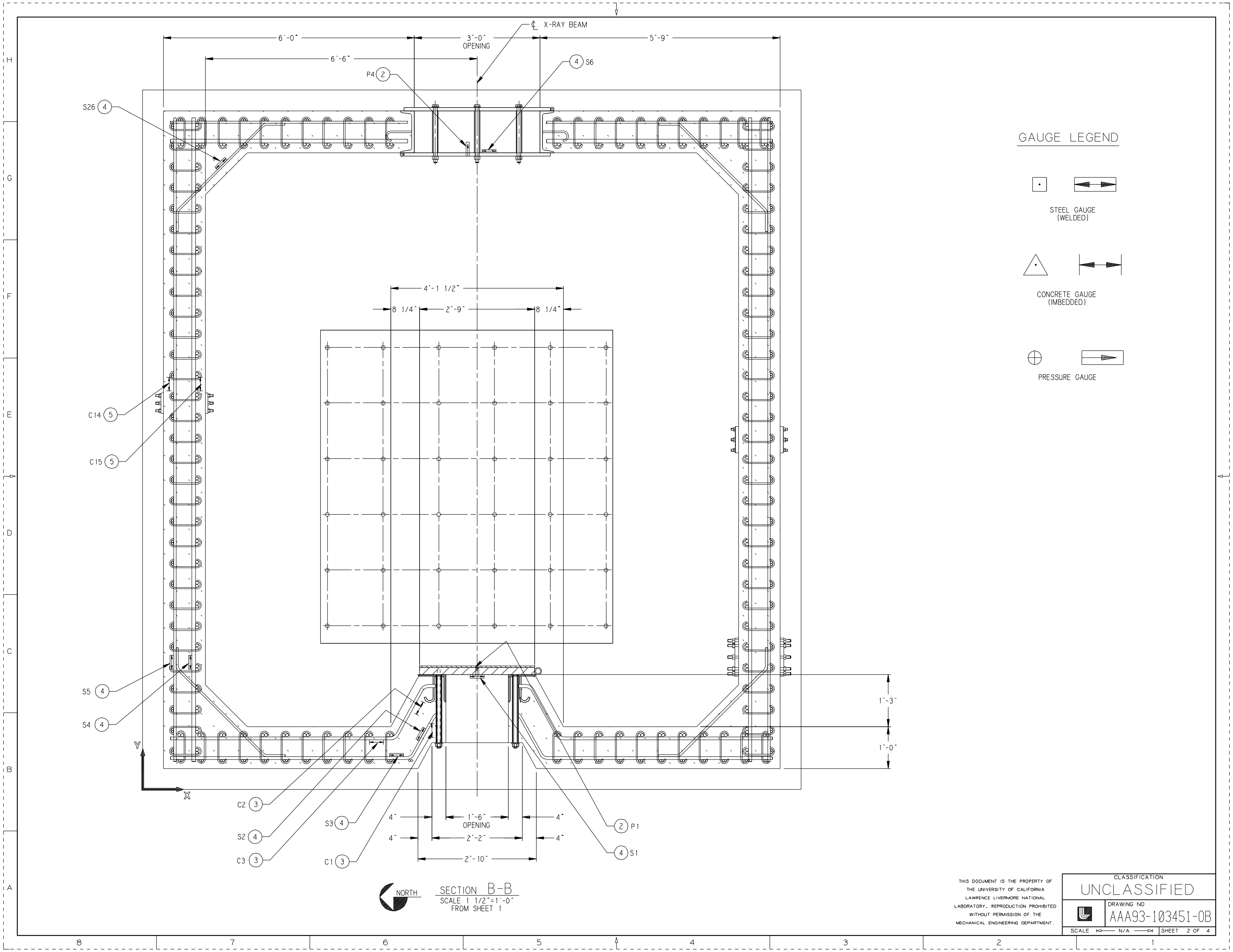
LTR	DWN	CHK	APVD	DATE	ZONE	CHANGE
A4	JWC	JP	JP	7/93		NO REQD- 29 WAS 16 (ITEM 4)
A3	JWC	JP	JP	7/93		NO REQD- 12 WAS 13 (ITEM 3)
A2	JWC	JP	JP	7/93		CHANGED GAUGE LOCATIONS
A1	JWC	JP	JP	7/93		ADDED GAUGE CHART

DWN S. KRAMER	8-92
CHK J.W. CLEMENTS	4-93
APVD J.W. PASTRNAK	4-93
CLASSIFIED BY:	
TITLE	DATE

LAWRENCE LIVERMORE NATIONAL LABORATORY
MECHANICAL ENGINEERING DEPT
UNIVERSITY OF CALIFORNIA

CLASSIFICATION

MAJOR UNIT (U) TITLES CLASSIFICATION
SITE-300 BUNKER-801
SUBASSY
1/4 SCALE CONTAINED FIRING
DETAIL
INSTRUMENTATION ARRANGEMENT
SHOWN ON AAA
DRAWING NO
AAA93-103451-0B
ACCT NO
5095-05
SCALE 4'-0"
SHEET 1 OF 4


X-RAY BEAM
6'-0"
3'-0"
OPENING
5'-9"
6'-6"
P4 2
4 S6
S26 4
GAUGE LEGEND
STEEL GAUGE
(WELDED)
CONCRETE GAUGE
(IMBEDDED)
PRESSURE GAUGE
4'-1 1/2"
8 1/4"
2'-9"
8 1/4"
C14 5
C15 5
S5 4
S4 4
1'-3"
1'-0"
Y
X
C2 3
S2 4
C3 3
S3 4
C1 3
4"
1'-6"
OPENING
2'-2"
2'-10"
2 P1
4 S1
NORTH
SECTION B-B
SCALE 1 1/2"=1'-0"
FROM SHEET 1
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CLASSIFICATION
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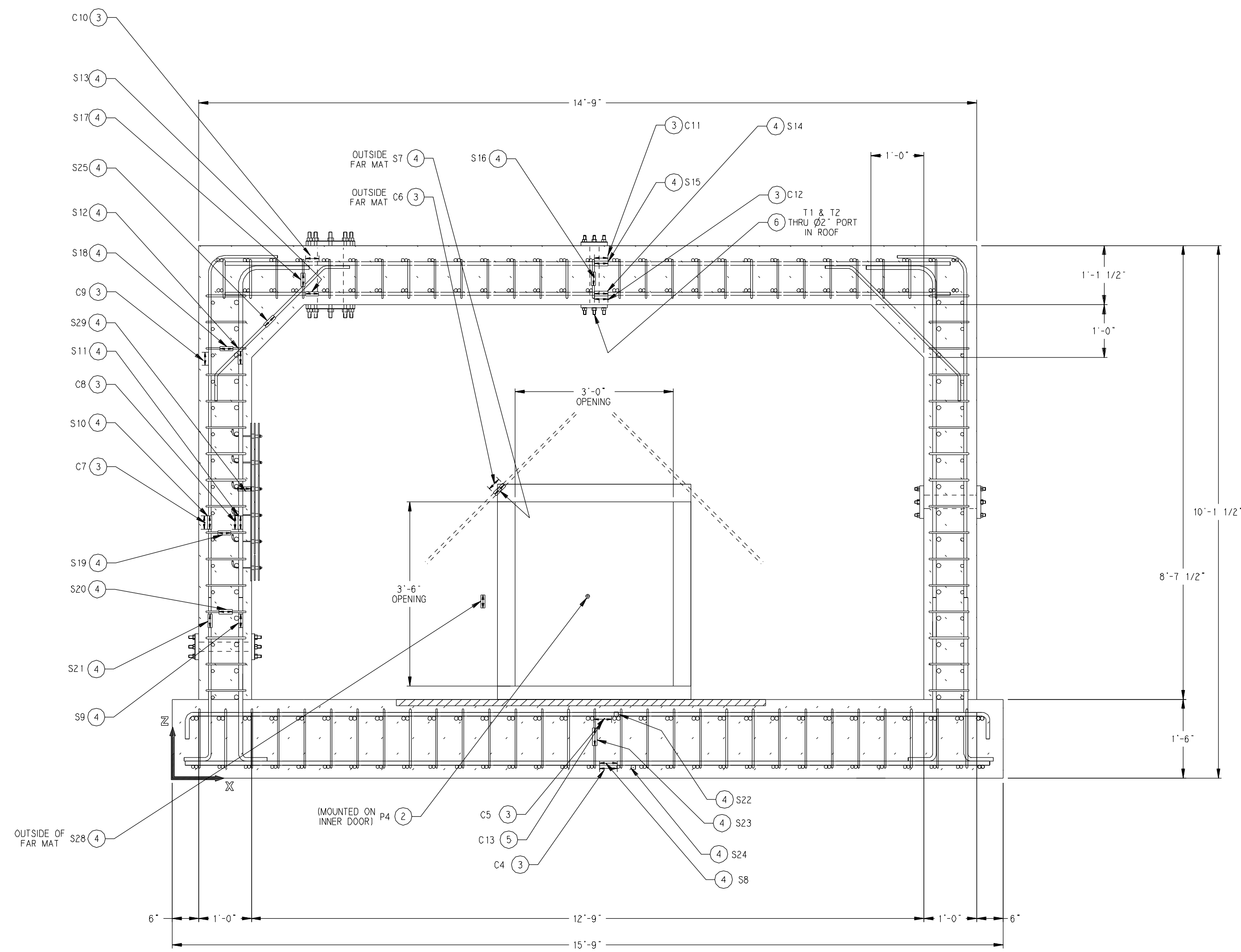
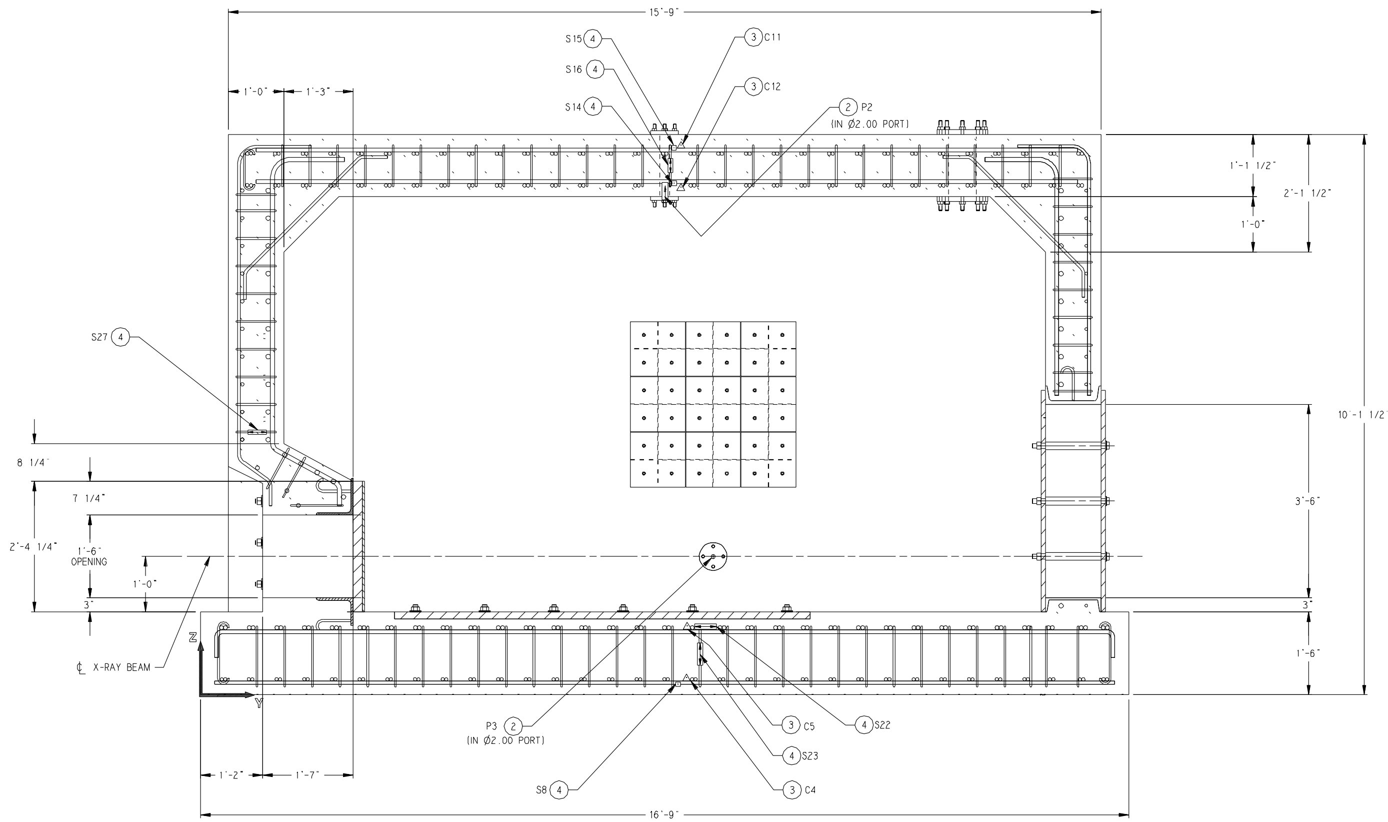
DRAWING NO
AAA93-103451-0B
SCALE N/A
SHEET 2 OF 4



SECTION C-C
SCALE 1 1/2" = 1'-0"
LOOKING EAST
FROM SHEET 1

CLASSIFICATION	UNCLASSIFIED
DRAWING NO	AAA93-103451-0B
SCALE N/A	SHEET 3 OF 4



SECTION D-D
SCALE 1 1/2"=1'-0"
LOOKING NORTH
FROM SHEET 1

CLASSIFICATION
UNCLASSIFIED

DRAWING NO
AAA93-103451-0B

SCALE N/A | SHEET 4 OF 4